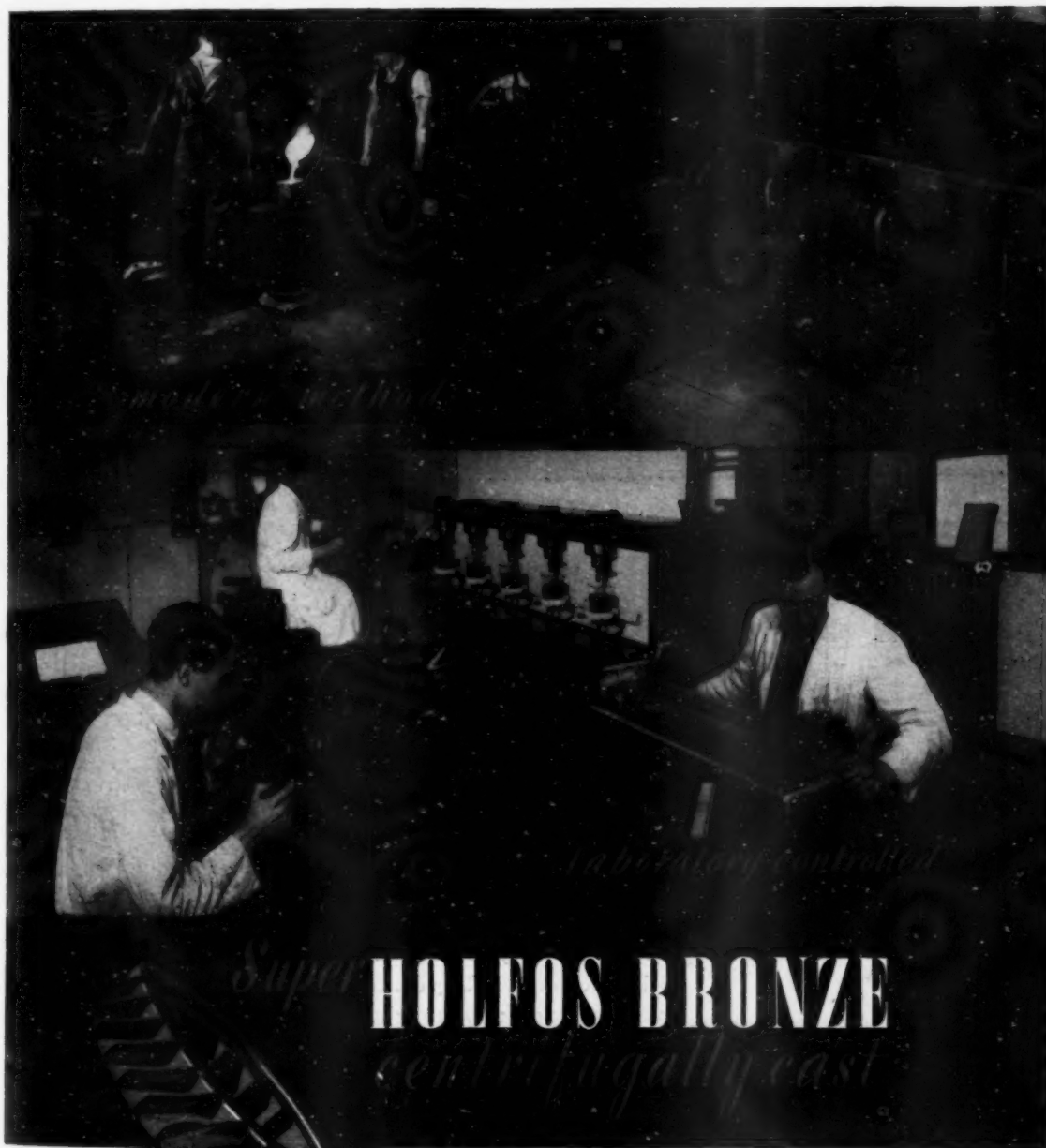


METALLURGIA

THE BRITISH JOURNAL OF METALS



Super **HOLFOS BRONZE** *centrifugally cast*



JOHN HOLROYD & CO LIMITED
ROPE STREET • ROCHDALE



McKECHNIE

BROTHERS LIMITED



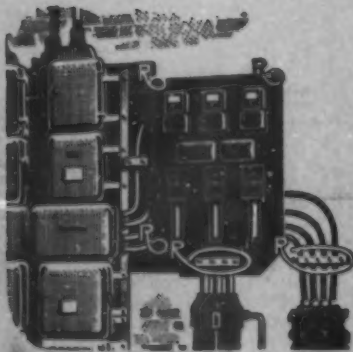
ROTTON PARK ST., BIRMINGHAM, 16 The Makers of "Tank" Brand

Non-Ferrous Metal Alloys, including:—

Extruded Brass and Bronze Rods and Sections, Brass and Bronze Stampings, Gunmetal and Phosphor Bronze Ingots, Chill Cast Gunmetal and Phosphor Bronze Bars, and Terne Metal and Cupro Nickel Ingots and Granules, regret their inability to satisfy all requirements of clients for their products for the time being,

When Peace returns to the World again, however, they look forward to being in a position to supply their old and new friends with all their needs of the Non-Ferrous Metal Alloys they produce and to be able to prove that once again "McKECHNIE" Products are second to none and that clients' complete satisfaction is their chief concern. In the meantime, they ask the indulgence of their friends and thank them for their understanding and the forbearance already extended to them.

SAVE TIME IN ELECTRICAL INSTALLATIONS



Save time, save labour, save tools—use Rawlplug Fixing Devices. Security and economy are assured, whether the job be one of light wiring or the fixing of the heaviest machinery. All over the country Rawlplug Fixing Devices are doing good work, making drastic cuts in the time taken to instal plant of the utmost importance.

Rawlplugs, Rawldrills, Rawltools, Rawlbolts, Rawldrives, Rawlplastic, White Bronze Plugs, Bolt Anchors, Screw Anchors, Cement in Sockets, Boring Tools, Tile Drills, Electric Hammers, Mechanical Hammers, Soldering Irons, Toggle Bolts and many products of Commercial and Domestic utility. Write for Technical Literature.

Contractors to His Majesty's Government.

THE RAWLPLUG CO., LTD., CROMWELL ROAD, LONDON, S.W.7

The World's largest Manufacturers of Fixing Devices

RAWLPLUG

FIXING DEVICES

Save Time

METALLURGIA

The British Journal of Metals
(INCORPORATING THE METALLURGICAL ENGINEER.)

★ The source of all matter extracted from this Journal must be duly acknowledged; it is copyright. ★

Contributions suitable for the editorial pages are invited. Photographs and drawings suitable for reproduction are welcome. Contributions are paid for at the usual rates.

PRINCIPAL CONTENTS IN THIS ISSUE:

	PAGE		PAGE
Surface Hardening by Quenching ..	1-2	The Formation of Hair-Line Cracks ..	22
<i>New machines for surface hardening by quenching are briefly described; they are additional to standard types available for the treatment of many kinds of components.</i>		The Basic Open-Hearth Process To-day. Part IV. By W. Geary ..	23-27
The Determination of the Solubility of Hydrogen in Iron and Iron Alloys ..	2	<i>Attention is directed to the improvements made in pit-side practice, especially to ladles, stoppers and nozzles, teeming speed and temperature, ingot moulds and their preparation, feeder heads, and bottom pouring. Instruments and fuel are also discussed.</i>	
Antimony—Its Occurrence, Production and Uses. By L. Sanderson ..	3-4	Rate of Oxidation of Typical Non-Ferrous Metals Determined by Interference Colours of Oxide Films ..	27
Remelted Aluminium for Castings ..	5	Hardness Testing of Heat-Treated Forgings. By Bernard Thomas, F.Inst.P. ..	28-30
Correspondence ..	6	<i>The variety of methods for hardness testing of heat-treated forgings frequently leads to difficulties in satisfying specification requirements. Tests are described which have been carried out on forgings of various weights.</i>	
<i>Heat-Treatment Response in Certain Non-Alloy Steels.</i>		Relaxation Resistance of Nickel-Alloy Springs ..	30
Unsoundness in 85-5-5-5. By William F. Chubb, Ph.D., B.Sc. ..	7-9	The Chemical and Physico-Chemical Analysis of Iron and Steel—Twelve Years' Advancement. By E. C. Pigott ..	31-33
<i>The alloy, comprising 85% copper and 5% each of tin, zinc and lead, is very widely used for many engineering purposes. When carefully compounded and properly cast it should be sound and free from internal porosity, in which case its mechanical properties will easily fulfil specification requirements. In this article the chief factor influencing the casting properties of this alloy is discussed by reference to failures which have been investigated.</i>		<i>Part II Continued. Papers describing the determination of single constituents.</i>	
The Use of Fired Small Arms Cartridge Cases in the Production of Some Alpha-Beta Extrusion Brasses ..	10-11	Desulphurisation in the Open Hearth ..	34
<i>Results are given from an investigation designed to determine the effect of the use of fired small arms cartridge cases on the properties of "straight" brasses containing 62, 59 and 56% copper on three standard leaded brasses and on one naval brass.</i>		<i>Investigations are described on the desulphurising power of calcium silicate steelmaking slags as affected by their iron-oxide content.</i>	
The Effect of Quenching and of Prolonged Tempering at 100° or 140° C. on Alpha-Beta Antimony-Chromium Tin Alloys ..	11	Reviews of Current Literature ..	35-36
A Metallurgical Study of German and Italian Aircraft Engine and Airframe Parts ..	12-21	<i>An Introduction to Aeronautical Engineering. Steels for the User. Engineering Questions and Answers. Tin Solders. Constitution of Alloys Bibliography. Anodic, Chemical and Paint Finishes for Aluminium and Its Alloys. The Polarographic Method of Analysis. Melting Furnaces for Grey Cast Iron.</i>	
<i>The report constitutes a summary of data resulting from the examination of German and Italian aircraft engine and airframe parts. In the present part, which is the fourth of the series, a summary is presented of the results of investigations on different types of gears, and also on some detachable bearings. The parts examined represent an extensive range from enemy aircraft which have fallen into the hands of the R.A.F.</i>		The Effect of Minor Alloying Elements on Aluminium Casting Alloys ..	37-39
		<i>With both primary and secondary aluminium so-called impurities are taken into the alloys, and the actions and effects of unwanted alloying elements are discussed in connection with the copper and copper-silicon-aluminium alloys.</i>	
		Purging Controlled Atmosphere Furnaces ..	39-40
		The Production in Rotary Furnaces of Steel for Castings ..	40

Subscription Rates throughout the World - - 24/- per annum, Post free.

Published Monthly by the Proprietors, THE KENNEDY PRESS LIMITED, at 21, Albion Street, Gaythorn, Manchester.

Telegrams: "Renprod," Manchester.

Telephone: Central 0098.



Why Waste Time

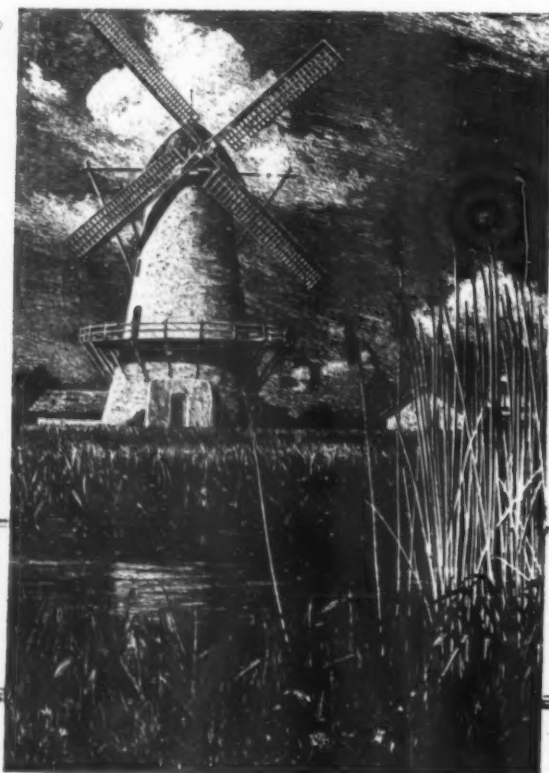
ON TOOL HARDENING WHEN YOU CAN BUY
TOOL HOLDER BITS
 HARDENED AND GROUND READY FOR
 NOSE GRINDING

3 QUALITIES:—

"SUB 66"	6% TUNGSTEN
"WUNDA"	6% COBALT
"TENCO"	10% COBALT

PLACE YOUR ORDERS NOW AS DELIVERIES ARE
 SOMEWHAT PROTRACTED

SANDERSON BROTHERS & NEWBOULD LTD. SHEFFIELD



*Founders
 in Aluminium..*

WILLIAM MILLS
 LIMITED,
 GROVE STREET,
 BIRMINGHAM 18.

Surface Hardening by Quenching

New Automatic Machines Developed for Mass Production

New machines for surface hardening by quenching are briefly described; they should prove a useful addition to the standard types available for the treatment of many kinds of components, and will increase the range of work capable of being treated by this method. The types described are designed to meet demands necessitated by mass production methods.

THE widespread use of carburised, cyanided and nitrided hard surfaces over a tougher core naturally led to the development of processes for the production of hardened surfaces by rapid heating of medium carbon steels and quenching them immediately a desired depth of the skin is heated above the critical temperature. Initial work indicated the necessity of a steep temperature gradient at the instant of quenching, to avoid hardening to too great a depth, and it was found that a high flame temperature was necessary to establish this steep gradient. The application of this principle is developed in the "Shorter" process, which has been in successful operation for many years. Initial work by this process was by hand, and the results were variable, since the timing of the sequence of heating and quenching required careful control. Gradually, however, mechanical devices for specific applications were developed, and the degree of control now possible is of a high order, and it is in this direction that great progress has been made in the application of this process.

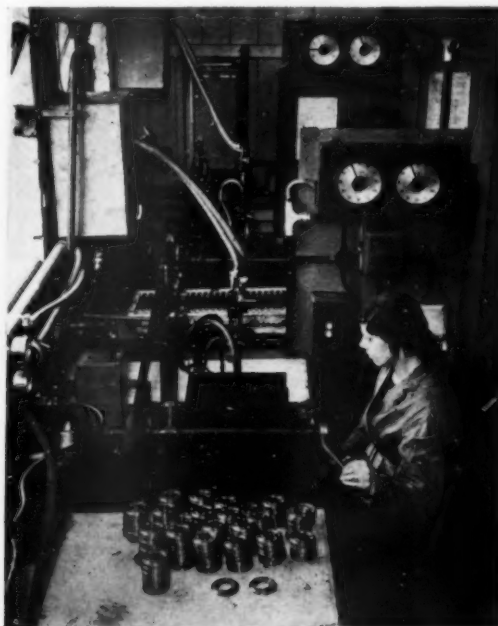
New applications are continuously being developed, and machines designed to facilitate the operation. Several of these machines have been introduced recently, some of which operate on a fully automatic basis and are being applied for the mass production of vital components required in the war effort which need surface hardening. Considerable interest is being shown, for instance, in the

Shorter Type N2 machine, which has several useful features. With this machine the components to be surface hardened are fed by hand, but apart from this the operation is under electrical control. The electrical equipment comprises two synchronous electric clocks, solenoid operated gas and water valves, relay panel, limit switch for starting automatic cycle, and a push-button system for testing and setting-up purposes. When the machine is being used on production the push-button station is not used. To harden a component the operator merely presses a lever which brings the burner into heating position; this lever actuates a limit switch which starts up the gas clock, which, in turn, energises the gas valve relay, thus opening the gas valve and a pilot light automatically ignites the gas at the burner. When the set heating time has elapsed the clock de-energises the gas valve relay and the burner is extinguished, and at the same time the electrical impulse is sent to the water clock, which starts up and energises the water valve relay, thus opening the water valve and quenching the component. After a given time has elapsed the clock de-energises the water valve relay and the water is shut off. The operating lever is then elevated, enabling

Fig. 1.—New surface hardening machine working on the treatment of firing pins.



Fig. 2.—Surface-hardening rings on a repetition basis.



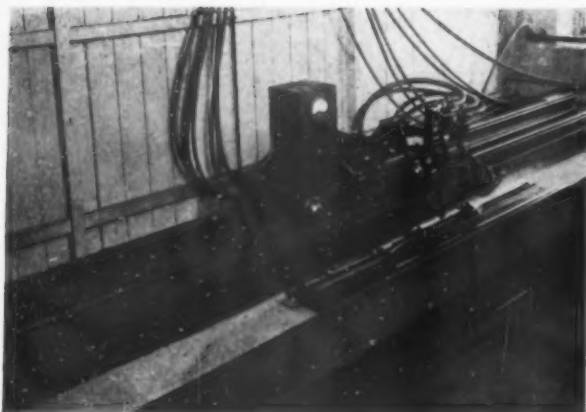


Fig. 3.—A new machine for surface hardening long straight-line surfaces.

the treated component to be removed and another inserted in its place.

The times of these two operations are checked by means of a stop-watch, and the clocks set to suit the requirements of the component to be treated. A trial run is then made, using the automatic control, and after making any necessary adjustments to the heating and quenching times, the machine is ready to treat these components on a production basis. Fig. 1 shows a machine of this type being applied to surface-harden firing pins. The hardening and tempering of these pins is being effected in a few seconds, and so accurate is the operation that, once the controls and regulators are set, it may be repeated indefinitely. The machine shown is hand fed, but types are under construction which can be hopper fed. In Fig. 2 a similar type of machine is shown being applied to the treatment of ring components.

A further interesting development is a machine built on similar lines, but with a rotary drum, hopper and trigger feed for small units, which enables components like engine tappet screws to be treated on the ends without manual handling other than feeding the hopper with quantities.

Blade Hardening Machine

Another recent development of considerable interest is a machine for the surface hardening of longitudinal surfaces, such as machine-tool beds, straight-edge, blades, multi parts fitted into jigs, and general straight-line work. This machine, known as the Shorter Type G 6 blade-hardening machine, is built on the lines of a machine-tool and has a longitudinal track of any desired length. It is illustrated in Fig. 3.

The machine is fitted with a Ward Leonard set, bus bars being fitted at the back with contactors fitted to the machine head. The control panel is fitted with a speed indicator. The machine can be fitted with automatic equipment for intermittent hardening; repetition parts can be laid in the long tank upon jigs, so that work can be progressing as the operator removes other parts that have been treated. Multi burners with multi gas jets fitted to the burner carriers are employed to cover any required width of face or number of faces to be treated simultaneously. Once the speed of the machine head has been adjusted to suit the particular component, no variation in speed can take place, thus the correct depth of hardness is maintained throughout the whole length of the traverse, and each similar component will receive the same treatment. By this arrangement the speed of the head operates between the limits of 1.4 to 14 in. per min.

Turntable Machine

The surface hardening of large circular work by this principle has previously been done by carrying the heating and quenching equipment on a movable head radiating

from the centre of the path to be treated and travelling upon the tread of the path. In a new type of machine, at present under construction, this method is superseded by mounting the rings to be hardened on a turntable which is rotated in relation to a stationary burner head and control panel. This machine is capable of treating very large paths, such as gun turrets, large circular crane tracks of any required width.

The vertical headstock spindle, provided with catch-plate for carrying jigs, is driven through a 5,000 to 1 gearbox by a 110 D.C. motor working in conjunction with a Ward-Leonard set, from which the speed control is obtained. Mounted on a circular plate carried by the headstock spindle are trips arranged to limit switches, controlling the rotation of the turntable and opening of solenoid operated gas valve through the medium of control equipment housed at the back of the control panel. By pressing a button, the gases are switched on, and when another button is pressed the turntable rotates. Gases are switched off automatically at any point of the traverse, and the position of switching-off may be pre-determined by the position of the appropriate limit switch. After one complete rotation the turntable stops automatically. In addition, test buttons for switching the gas "off" and "on," independent of the automatic arrangement, are provided; together with "inching" buttons for the turntable control, and push-button control of the Ward-Leonard set driving motor.

The speed can be varied to suit rings varying between 1 ft. and 9 ft. 4 in. diameter, the headstock taking a very large vertical thrust load.

These machines are a very useful addition to the number of standard types in application for many kinds of components, and will greatly increase the range of work which can be successfully surface hardened by this method, in addition, they will bring the treatment of many components well within the range of demands necessitated by mass-production methods.

The Determination of the Solubility of Hydrogen in Iron and Iron Alloys

THE solubility of hydrogen in various metals was investigated by Sieverts in 1910¹, and that research is generally regarded as the classical work on the subject. The value of much of the more recent work is open to question, because the investigators have used powdered metals in an attempt to reach equilibrium more quickly by increasing the surface area of the sample. At the same time reference to drawings of the apparatus used by Sieverts suggests that more accurate results should be possible with the improved experimental facilities now available, and it was thought desirable to repeat some of the work carried out by Sieverts, and, in particular, to investigate the effect of certain elements upon the solubility of hydrogen in iron alloys.

The results of the present work are reported* by Professor J. H. Andrew, Dr. H. Lee and Dr. A. G. Quarrell, in which the solubility of hydrogen in (i) iron, (ii) a low nickel-iron alloy, and (iii) a nickel steel at various temperatures has been determined by a method which is described. The authors show that hydrogen has no effect on the critical change of iron, but in the case of nickel-iron a sudden drop in solubility begins at a point corresponding to the peak on the thermal cooling curve and continues to a temperature of 475° C., which is 75° C. below the completion of the thermal change. This phenomenon was much more marked with the nickel steel, a fact which supports the view that carbon plays an important part in the retention of hydrogen in steel.

¹ Sieverts and Krumbhaar, *Berichte der deutschen chemischen Gesellschaft*, 1910, vol. 43, p. 895.

* Paper No. 5/1942 of the Alloy Steels Research Committee (submitted by the Hair-Line Crack Sub-Committee), presented for discussion by the Iron and Steel Institute, Advance copy, Sept., 1942.

Antimony: Its Occurrence, Production and Applications

By L. Sanderson

The properties of antimony of hardening and strengthening lead alloys and reducing contraction during solidification were recognised as early as the fifteenth century, but the majority of present-day uses in which these properties are important have developed in the past hundred years. A brief outline of the occurrence, production and uses of this mineral is given.

ANTIMONY is one of the oldest of known minerals, though many consider it was not recognised in its native condition until 1748. As long ago as the first century, and earlier, it was employed as a hair dye, eye-brow tinter, and eye-enlarger, from its ability to make the eye seem larger. The Greek name given to it in those days was the equivalent of "eye-expander." The alchemists called it "the wolf of metals." Oriental ladies used it medicinally, and to darken their eyebrows; and the Arabs and Hebrews know it to-day as "kohl." Actually, the form in which it was, and still is, used for these varied purposes is the sulphide mineral, "stibnite."

Later, in the sixteenth century, and possibly earlier, it was employed in making printers' metal, mirrors and bells. Even earlier—about 1500—its sulphide was employed for separating gold and silver, as well as silver and iron. Its medicinal use was as an emetic, for which purpose it was dissolved in wine.

The main sources of antimony are stibnite (Sb_2S_3), valentinite or antimony bloom (Sb_2O_3), senarmontite (Sb_2O_3), cervantite (Sb_2O_4), stibiconite ($\text{Sb}_2\text{O}_3 \cdot \text{H}_2\text{O}(?)$), kermesite ($2\text{Sb}_2\text{S}_3\text{O}_3$) and native antimony (Sb). Stibnite is usually discovered in confused aggregates of acicular or needle-shaped crystals. It has a metallic sheen, and is leaden grey in tint. It fuses readily and colours a flame green-blue.

Valentinite is usually found in fan-shaped or star-shaped groups of crystals. It has a lamellar structure, a distinct lustre, and is perfectly white, and translucent to just short of transparent. Senarmontite is octahedral in form, has a resinous lustre, and varies from translucent to transparent. It has little colour, some specimens, however, being pale grey, with white streaks.

Cervantite has needle-shaped crystals, a greasy or pearly sheen, and varies in tint from brown-yellow, yellow, to almost white. It is easily reduced on charcoal.

Stibiconite is pearly to earthy in lustre, pale yellow to yellowish-white in colour, some specimens being reddish-white, and is found in crusts or as a powder. Kermesite is usually found in tufts of hair-like crystals, and is cherry-red in tint. It is formed by the partial oxidation of stibnite, and is transformed by further oxidation into valentinite or cervantite. Native antimony is tin-white and very brittle.

There are also many antimonides of silver and other elements of metallic type, as well as a series of intricate sulphides and oxides, to enumerate which would occupy more space than can be spared. Antimony is also found in nature in alliance with arsenic, as in allemontite (SbAs), nickel as in breithauptite (NiSb), bismuth and lead in kobellite ($2\text{PbS}(\text{BiSb})_2\text{S}_3$), and with tin and lead in franckeite. All these, however, are minerals not of common occurrence.

The principal ore is stibnite. Antimony ores are found in rocks of practically every age. The veins proper are normally only rich at and near the surface, or to a moderate depth below it. Stibnite in the pure form is seldom found below a few hundred feet. The principal production of antimony ores in 1938 (Imperial Institute Statistical Summary) was Bolivia, with an export production of 9,287 long tons. Next came China with 8,000 tons; Mexico, with 7,907 tons;

Yugo-Slavia, with 3,370 tons; Algeria, 1,010 tons; and Peru, 662 tons. Other producing countries in order of importance were Italy, the United States, Turkey, Portugal, French Morocco, French Indo-China, Burma, Spanish Morocco, Southern Rhodesia, India, the Union of South Africa and Canada.

The figures quoted are in terms of metal. A number of other countries produce the ores, but for these information, as to output in terms of metal, is not available. They include Austria, Czecho-Slovakia, Greece, Argentina, Honduras, Japan and Korea. Of these only Czecho-Slovakia was of serious importance in 1937, the last year for which figures are available, when she produced 1,226 long tons of metal. Canada has never been a large producer of antimony, most of her ores being found in British Columbia, Nova Scotia, Ontario, Quebec and the Yukon.

Antimony itself is one of the group of elements containing nitrogen, phosphorus, arsenic and bismuth. It is, in the metallic form, silver-white, crystalline in structure, brittle, and has a considerable metallic sheen. Its specific gravity is from 6.7 to 6.86. Its melting point is 630°C . ($1,166^\circ\text{F}$.), and its boiling point approximately $1,300^\circ\text{C}$. ($2,372^\circ\text{F}$.). It volatilises at $1,500^\circ\text{C}$. ($2,732^\circ\text{F}$.). Its specific heat is 0.0523, and it possesses a coefficient of linear expansion of 11.5×10^{-6} per 1°C . Electrical conductivity is 4.2, and atomic weight 120.2. In chemical characteristics it has affinity with arsenic, but in other respects it has a closer resemblance to the metals zinc and germanium.

The mining of antimony is pretty much akin to that of normal quartz veins bearing base metals, and there are no exceptional problems attached to it. Some deposits are worked open cast. If the ore is found in big, ununiform deposits, special methods may be necessary for economical mining. In China very unsystematic and primitive mining methods are employed, if the word "method" can be used. According to Halse, the ore is taken wherever it is found, the vein being simply followed, the result being the leaving of chambers of irregular form and sometimes of considerable dimensions, with no support. Ventilation is virtually non-existent. Native-made black powder serves for blasting, and vegetable-oil flare lamps give light. The mine is rented out on contract, and the miners work on a piecework basis. In some of the mines, however, modern machinery is being installed.

Stibnite is so soft and friable, and so light in weight, that it is not economical to employ methods of water concentration, owing to the wastage that would occur as a result of slime formation; unless, of course, the ore contains high percentages of precious metals. Antimony sulphide can be concentrated by flotation. For this the ore must be finely ground. Creosote oils with sulphuric acid produce the greatest recovery percentages at the least expense. Re-treatment of primary flotation tailing raises the total recovery. In Southern Rhodesia some of the refractory antimonial gold ores are water-concentrated, and then oil-flotation follows.

Production of the metallic antimony is carried out in six different ways. The first is liquation to crude antimony, which is used for ores with more than 40% and less than 90% sulphide. Crude antimony itself has over 90% intermittent liquation is generally carried out in fireclay

Crucibles placed vertically in rows in an open fire, each row having a brick wall to separate it from the next. The bottom of each crucible has four or five holes to allow the liquid sulphide to fall into a receptacle of burnt clay. Where continuous operation is desired, tube furnaces, vertically located above receivers, or reverberatory furnaces having a tap-hole in the deepest point of the bed for removal of the liquated sulphide, have been employed. The liquation process is, however, wasteful because the residues have as much as 15% antimony left in them.

Production of metallic antimony from rich stibnite or from liquated sulphide must next be considered. Rich stibnite contains 60% of antimony. The ore is placed in crucibles made of a mixture of fireclay and plumbago on the bed of a long reverberatory furnace. The sulphide is first reduced by wrought-iron scrap, and the result is a metal termed "singles," made up of about 91.63% antimony, 7.23% iron, and 0.82% sulphur. To this is added some salt, which aids in slag formation and fusion of the gangue. The next charge comprises the metal produced by the first stage, common salt, and a quantity of liquated sulphide. The resulting metal is termed "star bowls," and is made up of 99.53% antimony, 0.18% iron, and 0.16% sulphur. Finally, the "star bowls" are mixed with antimony flux and liquated sulphide, and the result is "star" antimony, the ingots of which are commercially termed "French metal." The total loss due to volatilisation is in the region of 10%. The fume given off is collected in condensing chambers. In reverberatory furnace practice the two stages are fusion with scrap iron to produce crude metal, and refining fusion.

There used to be a method of treating poor ores, oxides, and liquation residues by simple roasting to tetroxide, but this is now obsolete. Poor ores are usually treated to-day by volatilising roasting. The most widely employed type of plant for this work is made up of a roasting furnace built of fire-brick, rectangular, and having a step grate of bar iron. The top part of the furnace communicates with a number of chambers furnished with condensation pipes of corrugated iron, or of iron with projecting fins, through which the air and dust are sucked by means of exhaust fans. Beyond the condensing chamber is a coke-tower.

Water passing from this lays down the final traces of uncondensed oxide. When the furnace is at the proper temperature the charge, comprising 50 kgs. of ore (containing from 15–20% antimony) together with about 2 kgs. of charcoal, is inserted. Roasting takes place at a maximum temperature of 400° C. (752° F.), and the result is a yield in oxide of at least 90% of the metal contained in it.

Antimony oxides, however produced, are reduced in small reverberatory furnaces by carbon in the presence of alkaline fluxes—e.g., crude sodium carbonate (soda ash), sodium sulphate (salt cake), and on occasion common salt. The furnace flue must be linked up with a condensing system of compartments or pipes. The metal is generally refined in crucibles or a reverberatory furnace.

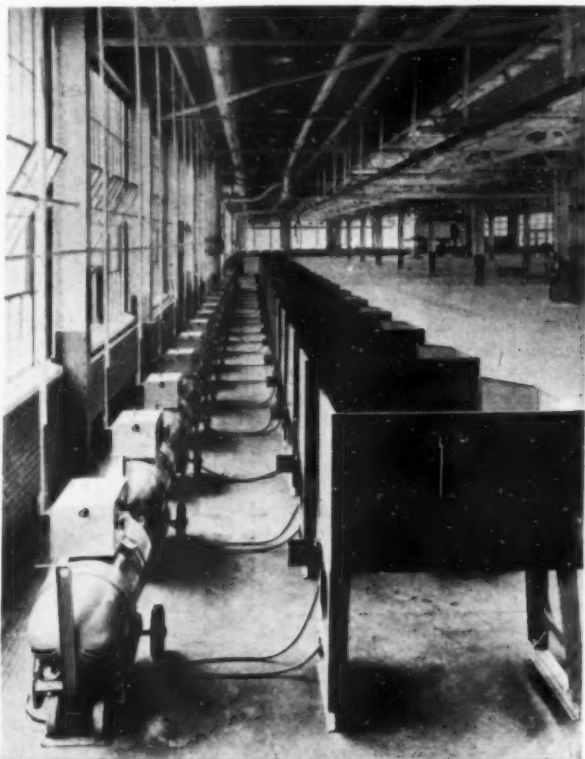
Direct processes for low-grade ore comprise smelting in a blast furnace with a tall shaft to lessen volatilisation, and a suitable condenser. Stibnite, slag and liquation residues with 25–40% antimony can be dealt with by this process, and iron is not needed for the reduction. Electrolytic methods of antimony extraction are known, but have not been commercially adopted.

Antimony has a wide range of commercial uses. In metallic form it can be precipitated from an acid solution of antimony salts by metallic zinc. It is then in powdered form, is termed "iron black" or "antimonial black," and is employed in giving a metallic appearance to pottery or objects of papier maché, to other metals, and to gypsum. Some of the sulphides are used for rubber colouring and vulcanisation, for making safety matches, and for making vermilion, orange-red and orange-yellow paints. Another use is to line lead chambers for making sulphuric acid. Yellow and blue pigments are also made with antimony sulphides.

Antimony oxides are employed in the manufacture of enamels; as a colouring agent in glass and pottery; in the preparation of artificial gems; as a pigment for hard porcelain, stoneware or glazed earthenware; as a water-resisting white paint. Blends of oxide and sulphide provide yellowish-red, dark brown and similar pigments. Antimony sulphide and dry carbonate of soda give a brown-yellow pigment.

Antimony salts are used as mordants—e.g., tartar emetic, for dyeing, thickening and decolourising. Tartar emetic is also employed as an emetic in medicine. Liquated antimony sulphide is employed in the priming caps of explosive shells. It is sometimes used in the shells themselves to give off a thick white smoke as an aid to range-finding. Sugar of antimony is used in furniture polish, and "antimony butter" (SbCl_2) is a fireproof for preservatives of wood, paper and textile fabrics—e.g., creosote, pitch, tar and asphalt. Antimonic acid is used in aniline manufacture.

The alloys of antimony are many, and include valuable metals such as the Britannia metal alloys, the bearing or anti-friction metals, the metals used for printers' type, the hard or antimonial leads, and a range of miscellaneous alloys of less importance, such as battery plate alloys, ships' nail alloys, metallic mirror and button alloys, jewellery alloys, and cable sheathing alloys. The principal metals with which it is alloyed are tin, lead, copper, zinc and bismuth. Gold is sometimes alloyed with it for jewellery manufacture. The antimonial leads are used for making shrapnel bullets, sheets for acid chambers, battery plates, chemical acid-resisting cocks and valves, and the like. This material is a by-product of lead smelting.



Courtesy of Lincoln Electric Company.

Welding booths installed by the Ford Motor Company for the training of arc welders to meet an urgent demand. The booths are occupied by 20 men, who receive intensive training. The arrangement is of a temporary character; as soon as a sufficient number of operators have been trained and are ready to go into production, the welding machines will be set up elsewhere in the Ford plant for actual production.

METALLURGIA

THE BRITISH JOURNAL OF METALS.
INCORPORATING "THE METALLURGICAL ENGINEER"

Aluminium Scrap for Castings

IN a previous issue* it was stated that the recovery of metal scrap and wastes, and their use with or instead of metals produced from ores is sound economics, and entirely in accordance with the general principle of conserving natural resources, that the stock of metal in use is no less a valuable resource than unmined ores. The principle has long been recognised in all metal producing industries, though it has been applied to a varying extent; certainly before the present war there was a tendency to use virgin metals, extravagantly. It is true that long before this war remelted or secondary aluminium was a recognised source of supply for a wide range of products, few of these, however, were applicable as components required in the war effort because specifications almost invariably stipulated the use of virgin aluminium in compounding the necessary alloys. Thus, no doubt due largely to the presence of contaminating substances there were important limitations to the use of remelted aluminium for many purposes.

Practically all commercial metals contain metallic or non-metallic elements which, for one reason or another, cannot be removed without considerable expense. Aluminium and its alloys are no exception to the rule. It is costly to purify aluminium to a purity of 99.9%, or higher. The purest commercial aluminium still contains a total of about 0.2% to 0.3% of such elements as iron and silicon, and others, such as sodium, titanium, manganese, zinc and gallium, in much smaller amounts. By far the bulk production of aluminium, however, does not attain this degree of purity. Where aluminium is combined with other commercial metals to form alloys, and it must be remembered that very little is now used other than as an alloy, other elements are carried into the alloys which are regarded as impurities. Even under the strictest methods of alloying and melting virgin metals, additions of other elements occur, and the more aluminium is remelted the greater is the tendency for these so-called impurities to accumulate.

Many other metals accumulate impurities, but in some cases it is possible to remove them by relatively simple operations. Aluminium can be purified electrolytically but the cost is too great to make it commercially practical for aluminium and aluminium alloys. Before the war plenty of good grade virgin aluminium was available, and the problem of unwanted minor alloying elements was not so vital. Then, it was easier to use virgin metal than metal remelted from scrap: to a very large extent it was necessary because of specification requirements, but there was some justification for suggesting that users were extravagant in the use of virgin aluminium. It is probable that the specifications for aluminium alloys were drawn up in this limiting fashion because information on the effect of minor alloying elements was not generally known, but the tremendous expansion in the use of aluminium as a result of the war, has strained the resources of producers and created

a shortage in supply of virgin metal. Under present conditions it has become necessary to use remelted alloys to the best advantage, and modifications have now been made in many specifications which permit the use of remelted or secondary aluminium. This situation is not new with the foundry industry, since remelted aluminium has been used successfully for many years, and the fact that this material is usable has been demonstrated by the substantial growth of the secondary aluminium industry. The main trend to-day seems to be to determine how many and what amounts of minor elements can be present without affecting the properties of aluminium adversely.

A characteristic factor of aluminium concerns the variability of the composition of the scrap. During the first decades of the use of this metal the scrap metal substantially contained, as alloying components, either copper or zinc, or both these heavy metals together. Iron also occurred as an impurity, this being partly due to the application of inappropriate melting conditions. With the extended use of the silicon alloys, silicon appeared in addition to copper and zinc. Foil constituted an important source of lead and tin as impurities in scrap aluminium, since lead and tin foil was often included in the melt. Nickel appeared in the remelted aluminium alloys, especially after the introduction of Y alloy and the R.R. alloys: magnesium, too, has become increasingly present as an impurity of scrap aluminium, since alloys of the type of Birmabright and Magnalium were introduced. The rapid development of new types of alloys naturally produced fluctuations in the nature of scrap metal, and, in some cases, the scrap metals do not correspond, even fundamentally, in their composition with newer alloys.

In addition to the various alloying elements present in scrap, various non-metallic impurities also contaminate the scrap. It may contain dirt, paint, oil, water, silica, aluminium oxide, wood and other organic substances, and, unless such scrap is carefully sorted and graded, the secondary metal produced from it may contain aluminium oxide, aluminium carbide, aluminium nitride, and such dissolved gases as hydrogen, carbon dioxide, and hydrocarbon gases. Many of the problems of contamination of aluminium scrap are now solved by proper sorting and grading, and much can be done by suitable treatment in the remelting operation to make the secondary metal of good quality. The operations in the works of many producers are carried out under strict control, and in many respects the remelted metal compares favourably with certain grades of virgin alloy ingots.

If clean scrap is used, and it is carefully graded under controlled conditions, the most favourable results will be obtained, but, normally, during the remelting of scrap metals, the introduction of unwanted elements is almost unavoidable. It is impossible, for instance, to separate mixtures of borings of several aluminium alloys, mixed sheet scrap, or other similar materials, and, to-day, such

INDEX TO VOL. 26.

In view of the paper shortage, and to avoid waste, it is not proposed to issue an index for Vol. 26 for general circulation. Readers who desire this index are asked to advise us, as copies will be prepared and dispatched on request.

The fact that goods made of raw materials in short supply owing to war conditions are advertised in "Metallurgia" should not be taken as an indication that they are necessarily available for export.

elements as copper, zinc, manganese, magnesium, iron, chromium, nickel, silicon, lead, tin, bismuth, titanium find their way into aluminium alloys. If sodium and calcium are added to this list, then there are 14 common elements in aluminium alloys which may be desired alloying elements, innocuous or harmful.

Much of the work done on the effect of minor alloying elements on aluminium casting alloys has been concerned with virgin metal rather than complex compositions

obtained when scrap is remelted, but an important contribution to our knowledge of the action and effect of so-called impurities in aluminium casting alloys is discussed elsewhere in this issue. Their influence is considered in respect to the physical properties of the alloys, and the information given should assist users in the application of reliable secondary aluminium alloy ingots for castings and give them greater confidence in making proper selection from the various types available.

Correspondence

Heat-Treatment Response in Certain Non-Alloy Steels.

The Editor, METALLURGIA.

Dear Sir,

In the above article, published in your October issue, Mr. Thomas appears to have overlooked B.S. 970, En. 10-50 carbon steel (hardened and tempered), which is the same as En. 9 as regards chemical composition, excepting for an unimportant variation in manganese content. It is stated in the article that normally En. 9 is not used in the heat-treated condition, whereas En. 10 covers the same steel in the heat-treated condition.

That variation in the manganese content of carbon steels affects response to heat-treatment is a well-known fact, and for that reason it is often necessary to modify the heat-treatment procedure to suit carbon-manganese relationship of any specific steel, particularly with the water-hardening carbon steels, if excessive distortion and the development of quenching cracks is to be avoided: the manganese should vary inversely to the carbon content if a standard procedure is to be maintained.

Mr. Thomas has not included in this article the usual mechanical properties of the various samples tested, although it appears that at least one series were tempered to Brinell hardness of at least 400-500. The bend test apparatus employed is of unusual type, and has presumably been used in the absence of a normal testing machine which would have given a better opportunity of studying the behaviour of the steel in this test.

The use of the abbreviations "T.S." and "P.S." is confusing, as they usually indicate "tensile strength" and "proof stress" respectively.

The temperature of the fused salt quenchant is not quoted, but the hardening procedure appears to be a form of "austempering," and would produce an acicular intermediate structural product. Such a method of treatment may be applicable on tools and components produced in small quantities, but the greatest tonnage of this class of steel is used for general engineering purposes and will have to be hardened in the normal manner in oil.

Mr. Thomas is to be congratulated on approaching the study of this steel in an unconventional manner, but the value of the article would have been greatly enhanced by a record of the general properties as determined by tensile, impact and hardness tests on all samples, together with a record of their microstructure.—Yours faithfully,

R. J. BROWN,

Chief Chemist and Metallurgist, Morris Motors, Ltd.,
Engines Branch.

Coventry, October 31, 1942.

The Editor, METALLURGIA.

Dear Sir,

Many thanks to your correspondent, Mr. R. J. Brown, for his comments in connection with my article on "Heat-treatment Response in Certain Non-Alloy Steels," which appeared in your October issue. In reply, I would say that one of the objects of the article was to remind users of the influence of manganese in straight-carbon steels, now that there is a greater likelihood of these steels being used. While it should be a well-known fact how manganese

content affects the response in a carbon steel, it is a continual source of surprise to me how frequently this point is ignored. That manganese should vary inversely to the carbon content was a subject dealt with in these pages on a previous occasion.*

For your correspondent's information, a very large tonnage of steel of the character described is used in the production of tools and components to an extent, in this area at least, greater than that used for general engineering purposes. With such tools it is standard practice to quench in fused alkaline salts at temperatures of approximately 160°-180° C. Experience has shown that quenching in this manner is capable of producing a fully martensitic structure where the acicular needles are much finer and consequently less brittle in comparison with results obtained by quenching in oil.

Mr. Brown will appreciate the limitations of salt-bath quenching, and it is for this reason that the tests on strips, as described, were necessary, as it is not possible to obtain consistently a thorough quench on a test-piece of the size suitable for obtaining the usual mechanical tests, and the frequency with which a pearlitic core was prevalent rendered such tests valueless on our normal testing facilities.

The possibility of confusion by use of the abbreviations "T.S." and "P.S." is regretted, but in view of the need for conservation of space, it was felt that the explanation, as given on page 200, was sufficiently clear in this respect.

A record of micro-structures applicable could, of course, have been submitted, but there have been so many published in relation to steels of similar nature that it was considered unnecessary in view of space consideration.—Yours faithfully,

B. THOMAS,

Managing Director,

Midland Heat Treatments, Ltd.

Wolverhampton, November 5, 1942.

*METALLURGIA, Oct., 1934, pp. 179-190.

Forthcoming Meetings

Iron and Steel Institute.

Nov. 17. Joint meeting with the Lincolnshire Iron and Steel Institute at the Modern School, Cole Street, Scunthorpe, at 7.30 p.m. Mr. A. Robinson, president of the Lincolnshire Iron and Steel Institute, will preside, and the following papers will be presented for discussion:—"The Linings of Large Basic Open-hearth Tilting Furnaces," by Mr. A. Jackson; "Investigations on 'Falling' Blast Furnace Slags," by Dr. T. W. Parker and Mr. J. F. Ryder.

Sheffield Society of Engineers and Metallurgists.

Dec. 12. Dr. W. H. Hatfield, F.R.S., will preside at a meeting of the above Society, held at the Royal Victoria Station Hotel, Sheffield, at 2.30 p.m., when Mr. H. Bull will lecture on "Economic Utilisation of Alloy Steel Scrap in Steelworks."

Manchester Metallurgical Society.

Nov. 18. At 4.30 p.m., at the Engineers' Club, Albert Square, Manchester, Dr. W. J. Rees, F.I.C., will lecture on "Refractory Materials."

Unsoundness in 85—5—5—5

By William F. Chubb, Ph.D., B.Sc.

The alloy, comprising 85% copper and 5% each of tin, zinc and lead, is very widely used for many engineering purposes. When carefully compounded and properly cast it should be sound and free from internal porosity, in which case its mechanical properties will easily fulfil specification requirements. In this article the chief factor influencing the casting properties of this alloy is discussed by reference to failures which have been investigated.

AS is well known, one of the most useful alloys for general non-ferrous casting purposes is that known as 85—5—5—5, a copper alloy composed of approximately 85% of copper and 5% each of tin, zinc and lead. In the early days of its production this alloy was commonly called ounce metal by founders, for the reason that it was prepared by adding to 1 lb. of molten copper 1 oz. each of the three additions named, the resulting alloy then having a composition approximating to 85—5—5—5. In modern times, however, this alloy is widely known both in England and the United States as "eighty-five three fives," the derivation of this being obvious.

In its applications 85—5—5—5 is employed for general utility purposes demanding a reasonable degree of strength and satisfactory corrosion-resisting properties. For these reasons it has been widely adopted in the production of pressure castings, and in not a few instances also has been specified for bearings. A further, but somewhat limited, use for this alloy has been found in general engineering applications at temperatures not exceeding about 230° C. It is accordingly one of the most widely used non-ferrous alloys, particularly on account of its relatively low cost.

Specifications

The analytical composition to which this material is made is approximately the same in England as in the United States and Canada, and for this reason A.S.T.M. designation B. 62-41 may be quoted as perhaps representative of alloys produced on both sides of the Atlantic. This specification, originally issued in 1936, was revised in 1941 to the following:—

	Minimum.	Percentages.	Maximum.
Copper	84.00	Desired. 85.00	86.00
Tin	4.00	5.00	6.00
Lead	4.00	5.00	6.00
Zinc	4.00	5.00	6.00
Iron	—	—	0.25
Nickel	—	—	1.00
Phosphorus	—	—	0.05

In the United States of America most 85—5—5—5 is made from refined ingot under A.S.T.M. specification B. 30-41, Grade, 4, but the chemical specifications for ingot metal are different from those for castings, and for that reason should not be substituted for them.

The tensile properties demanded in A.S.T.M. specification B. 62-41 are:—

Tensile strength, min.	30,000 p.s.i.
Yield point, min.	14,000 p.s.i.
Elongation in 2 in., min.	20%

It may here be noted that while the minimum tensile strength specified is 30,000 p.s.i., good foundry practice will, usually provide alloys averaging 33,000 p.s.i., and experience shows that by maintaining a strict technical control even higher tensile properties may be obtained. Much depends, however, on the relative proportions of zinc and tin present within the limits imposed, for increase of tin increases the hardness appreciably and results in a general stiffening of the cast material, while zinc acts in



Reduced on reproduction to 1/2 linear.

Fig. 1.—Macrostructures of "Good" and "Bad" castings. x 1.

an essentially similar manner but to a lesser extent. Also lead tends to decrease the tensile strength and ductility, its major purpose being, of course, that of improving machinability, so that within the ranges of composition allowed there may be a very wide range of tensile properties reported.

In England the mechanical properties usually obtained are:—

Tensile strength	13—16 tons/sq. in., min.
0.1% proof strength	5 tons/sq. in., min.
Elongation	15—35%
Diamond hardness	60—70.

the material being classified generally as a leaded gunmetal.

Two other American specifications govern this material, namely, S.A.E. 40 and Federal QQ-B-691 of Composition 2, these being practically identical in all respects with A.S.T.M. B. 62-41.

Structure

In its general structure this alloy is very similar to that of a bronze containing between about 7 and 8% of tin. Sand-cast alloys of this type are characterised by a well-pronounced coring, and in 85—5—5—5 the alpha-delta eutectoid is generally not present. Occasionally, however, it may occur in small amounts. In this cored matrix may be seen many small globules of lead, this being relatively insoluble in the copper matrix, and because of its low-melting point being more usually present in the dendritic fillings. When properly cast 85—5—5—5 should be sound and free from internal porosity, but the chief factor influencing its casting properties may perhaps best be

discussed by reference to failures occurring in castings made from this alloy.

The investigation now to be described affords an exceptional instance of unsoundness in 85-5-5-5 leaded gunmetal in that certain specimens necessarily examined in close detail exhibited nearly all the common faults likely to occur in castings made from this material. To render their influences clearer a comparison has been made between good and bad castings, and the investigations so undertaken have accordingly included in each instance very complete analyses, with details also of both macroscopic and microscopic examinations.

Analyses

This investigation is related to the production of faucetets in 85-5-5-5 and examination of rejected castings revealed a visible degree of porosity with very roughened surfaces. Evidence of tin sweating was very pronounced, suggesting the possible presence of undesirable impurities, for, as will be well known, the casting properties of this alloy are greatly influenced by impurities, both metallic and non-metallic. It would appear that in both instances the alloys were deficient in tin, the analyses of "good" and "bad" castings being as follows:—

	"Good" Casting.	"Bad" Casting.
Copper	85.49	85.18
Zinc	5.87	4.87
Lead	5.40	5.80
Tin	3.10	3.80
Phosphorus	0.005	0.007
Nickel	0.05	0.00
Bismuth	0.05	0.05
Arsenic	0.015	0.03
Antimony	0.11	0.12
Aluminium	0.02	0.04
Silicon	0.03	0.004-0.006
Sulphur	0.021	0.006

It will be observed that the deficiency in tin is greater in the case of the "good" casting than in the case of the "bad" casting, and it is accordingly of interest to discuss these analyses in the light of the known influences of each element present upon the casting properties, soundness, mechanical and other properties upon which the production of acceptable components must necessarily depend.

Influences of Impurities

The presence of phosphorus in these alloys is naturally due to its use as a deoxidizer, and as those conversant with the quantity of production of castings in 85-5-5-5 will know, only a trace of this element need be retained in the final alloy. Any excess of phosphorus over and above the maximum permitted in leaded gunmetal specifications only results in an unnecessary lengthening of the solidification range, thereby increasing the tendency to unsoundness, and it has a further tendency to harden the metal appreciably. In certain instances it may also promote the formation of rough surfaces. On the other hand, it will be appreciated that phosphorus increases markedly the fluidity of the metal, but it is always as well to keep within the specified maximum—that is to say, 0.05%.

As detailed earlier, American specifications provide for possible additions of nickel up to a maximum of 1.00% at the option of the manufacturer, and it may be said that within this limit the presence of nickel is generally beneficial. Larger amounts of this element, however, break up the coiled structure characteristic of 85-5-5-5, and have a very pronounced influence in rendering the alloy sluggish in pouring. As will be clear also, the initial freezing point is raised, and in accordance with the general influence of nickel upon copper-base alloys the colour of the material is changed noticeably.

In so far as bismuth is concerned, it is sometimes claimed that this element is decidedly harmful, but it is worthy of note that many American and English specifications for leaded gunmetal have not so far defined permissible limits for this element. Similar remarks apply in general to the presence of antimony, although many authorities have claimed that it is relatively harmless. In this matter, however, it would appear that the deciding factor is not

so much the actual amount of the element present, but the form in which it exists; a question which is best studied from the results of microscopic examination. In the same way aluminium may, or may not, be harmful in its influences upon 85-5-5-5, for if the metal contains aluminium in the form of oxide this has a decided detrimental effect upon casting qualities, while in solution its harmful influences, if any, are more difficult to establish. There is evidence, however, to show that even in alloyed condition aluminium may render castings of 85-5-5-5 very unsound since it affects very appreciably the crystallisation characteristics of this alloy. In addition, aluminium is generally believed to be a major cause of tin sweat, such as that observed in the present instance, and there is ample evidence in support of this contention.

As regards sulphur, this element does not appear to affect either the casting qualities or the physical properties of this alloy to any appreciable extent provided there is no tendency to promote the formation of sulphide inclusions. If this tendency, however, becomes very pronounced the properties of the alloy are greatly affected, but in the present instance there is no evidence to suggest that sulphur has in any way been contributory to the poorness of the castings.

Lastly, with reference to silicon, all the experimental evidence so far collected leads to the very definite conclusion that this element is harmful in 85-5-5-5, even when present in relatively small proportions. It has, in fact, been reported that the presence of but 0.03% of silicon can be the direct cause of unsoundness, this being due in large measure to the more ready formation of dross by interaction between compounds of lead and silicon. In the present instance, however, the presence of 0.03% of silicon on the "good" casting does not appear to have had any very obvious deleterious effect, but in the case of the "bad" casting it should be noted that the variation in silicon content was so great that concordant results in analyses could not be obtained. This fact points to the conclusion that the actual variation in silicon content is likely to be even greater than that recorded, and it further suggests that instead of being present in solid solution the silicon exists in the "bad" material in an insoluble form, such as oxide, very non-uniformly distributed throughout the castings.

As a result of this short discussion it will be clear that from the analyses alone it is possible to suggest several contributory causes of failure in this alloy, the chief being a very variable silicon content which would have a very appreciable influence on the casting qualities. It is accordingly of some considerable interest to examine closely the macrostructures of these two specimens.

Macrostructures

In Fig. 1 are reproduced at three-qtrs. size the macro-sections prepared from a "good" and a "bad" casting by cutting longitudinally, polishing and deep etching with acid-ferrie-chloride. These serve to illustrate that in general the "good" casting has the finer structure of the two, and they also serve to illustrate the fact that such difference in macrostructure as may be seen are most clearly visible in those sections in which leakage and porosity has been most pronounced. There is evidence also to suggest that the relatively much larger grain size of the "bad" casting may be accounted for, at least in part, by the higher casting temperature employed in this instance. As will be evident, these conditions have produced much slower cooling and a consequent coarsening of the grain structure.

Micro-Examination

To secure further evidence as to the poor quality of these castings, and by way of further comparison between "good" and "bad" material, an examination of the microstructures is of considerable importance and significance in determining the ultimate cause, or causes, of

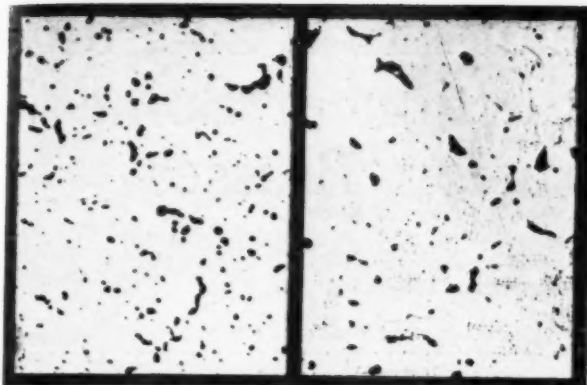


Fig. 2.—"Good" casting, unetched, showing distribution of lead. x 100.

Fig. 3.—"Good" casting, unetched, showing distribution of lead. x 200.

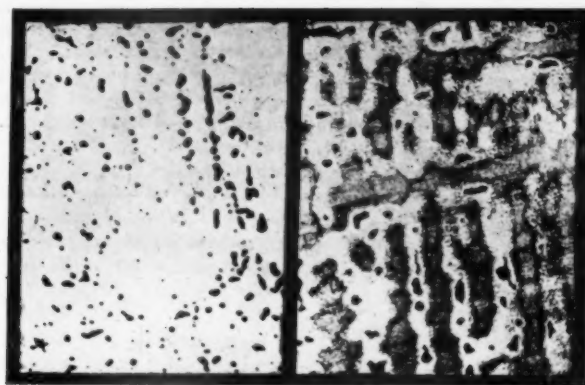


Fig. 4.—"Bad" casting, unetched, showing lead segregation. x 100.

Fig. 5.—"Bad" casting, etched acid ferric chloride, showing pronounced coring and non-uniform distribution of lead. x 200.

failure. These micro-sections have been prepared in positions where cracks and other surface irregularities or defects had been noted. Thus, in the unetched condition, depicted at a magnification of 100 in Fig. 2, the condition of the lead in the "good" casting is clearly seen to be uniformly distributed throughout the section. Also, there is here little or no evidence of internal porosity or of blow-holes, and these general observations are confirmed in Fig. 3, which illustrates a similar section at the higher magnification of 200, for there is again little evidence of segregation and the lead is uniformly distributed. Little oxide can be seen at this higher magnification, and the structure may accordingly be regarded as very satisfactory in every way.

Turning to the "bad" casting, the structure obtained will be seen to be very different from those previously described, for in the unetched condition in Fig. 4 this casting exhibits a fairly pronounced segregation of lead; while in the etched section of Fig. 5 the pronounced coring, characteristic of leaded gunmetal, is clearly revealed at a magnification of 200. Other sections similarly examined revealed evidence of internal porosity.

Summary

On the basis of the above evidence certain deductions as to the causes of poor casting qualities appear to be possible. While the analytical evidence alone does not enable any very definite conclusions to be reached in this respect, the higher aluminium content of the "bad" casting, and more particularly the very variable silicon content of this material, suggests that oxides may have contributed to the causes of failure to produce sound castings. This is in general confirmed by the discoloured condition of fractures in certain sections of the material, and the microscope reveals unmistakable evidence of internal porosity in these sections. For confirmatory evidence, the structures of alloys which provide very discoloured fractures may be examined.

Discoloured Fractures

As discoloured fractures appear to be associated very frequently, but not always, with poor castings, it is of interest to report on the microstructure of such castings with a view to ascertaining their cause. In this particular instance the fracture obtained was of brick-red colour, but it may be noted that in other instances of bad casting qualities almost black fractures have upon occasion been observed. A typical microstructure of a badly discoloured fracture is provided in Fig. 6, where, in the unetched section, lead segregation is clearly to be seen. This is also associated with a pronounced degree of porosity, the most probable cause of which is either shrinkage or gassing during solidification. Of these two possible causes, gassing would seem to be the more likely in this instance.

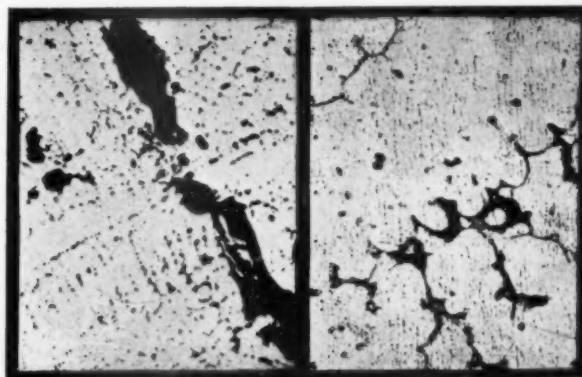
It will also be seen that this casting contains fair amounts of oxide, chiefly of copper oxide and silica, and this is more clearly illustrated at the higher magnification of Fig. 7. This section depicts an area which contains less than the average percentage of lead, and in which undesirable oxide inclusions are clearly visible. As illustrated, the section is also very porous, internal cracks being in fact very numerous throughout this casting. Hence, from the above evidence, it seems clearly proved that discoloured fractures are chiefly due to oxide inclusions, to porosity, and to gassing during solidification. When this occurs the remedy would appear to lie in a more complete deoxidation of the melt, and in the prevention of lead segregation locally in the casting. Strict control of casting temperature is obviously very necessary in casting 85-5-5-5 leaded gunmetal.

Conclusion

The above instance of failure in 85-5-5-5 leaded gunmetal is of considerable interest in offering an exceptional illustration of the many possible sources of unsoundness in this material. Among the unusual features noted are a general deficiency in tin, a higher aluminium content in castings characterised by tin sweating, a pronounced variation in silicon content throughout the material, high arsenic and antimony contents, a general unsoundness of structure, with much internal porosity, lead segregation, and inclusions of oxide, which may be regarded as the most probable cause of discoloured fractures. From the above discussion it should not be difficult to assess the relative importance and significance of each observed defect.

Fig. 6.—Discoloured fractures due to internal porosity. x 50.

Fig. 7.—Discoloured fractures, showing internal porosity, oxide inclusions and general unsoundness. x 200.



The Use of Fired Small Arms Cartridge Cases in the Production of Some Alpha-Beta Extrusion Brasses

Results are given from an investigation designed to determine the effect of the use of fired small arms cartridge cases on the properties of "straight" brasses containing 62, 59, and 56% copper, on three standard leaded brasses, and on one naval brass.

VARIOUS troubles have been associated in the past with the use of scrap-fired cartridge cases, with the result that they have generally been avoided by manufacturers, except for low-grade work. The detrimental influence of the cartridge cases has usually been attributed to the presence of small percentages of either antimony or mercury, introduced by the explosive mixture in the cap; the effect of this is generally considered seriously to impair the elongation of brasses, in the making of which scrap cases have been used. In order to determine whether fired 0.303 in. cartridge cases could be safely used as scrap in the production of some extrusion brasses, and to obtain certain data on the subject, an investigation has been carried out the results of which form the basis of a recent report by John Rae, jr.

As a preliminary, the composition of the explosive mixtures used in the cap was ascertained, and the amount of antimony present before firing was found to be 1% of the weight of the unfired case, in the form of antimony sulphide. A considerably smaller percentage of mercury is present, but it is thought to be very unlikely that any of this would remain after remelting, owing to the low volatilisation point of mercury; this view was confirmed by later experiments.

Tests were carried out under full production conditions, the heats being melted in half-ton low-frequency induction furnaces and poured into 6½ in. diameter water-cooled moulds; the billets so produced were extruded under normal conditions and at a temperature suitable to the composition of the alloy concerned. Standard war-time mixtures containing a large percentage of scrap were used, the cartridge cases replacing copper and spelter as far as possible, and in each case comparative heats were made without cartridge-case additions. Added antimony was introduced after the melt in the induction furnace had been skimmed. Rods were tested in the "as-extruded" condition, except in the case of drawn leaded brass, the drawing of which was carried out cold in the normal manner. Test-pieces were taken from the middle of the rods.

Three alloys, of the nominal compositions given in Table I, were extruded into rods of the diameters shown.

TABLE I.

Alloy No.	Diam. of Rod, In.	Copper, %	Zinc, %	Alpha approx. %
1	1	62	38	75
2	1½	59	41	60
3	1½	56	44	10

In practice, Alloy 1 is used for applications requiring good cold-working properties, and is usually specified where cold riveting is required. Alloy 2 is used for similar purposes, but where the degree of cold work is not so great, and also for applications requiring a lead-free alloy. Alloy 3 has little commercial use, but was made up to ascertain the effect of antimony on a practically all-beta alloy. The compositions of the three alloys are given in Table II.

In addition to the "straight" brasses, given in Table I, three typical leaded brasses were used in the series, and also a naval brass.

From the results recorded in the report, the primary fact emerges that antimony, introduced from the explosive

TABLE II.—CHEMICAL COMPOSITION OF "STRAIGHT" BRASSES.

Alloy No.	Mixture No.	Clean Fired Cases Used, %	Muffled Cases Used, %	Chemical Composition, %					
				Copper.	Tin.	Lead.	Iron.	Nickel.	Antimony.
1	A	Nil	Nil	61.7	Trace	0.06	0.05	Trace	0.002
	B	60	Nil	61.9	Trace	0.06	0.05	Trace	0.012
2	A	Nil	Nil	59.1	0.006	0.05	0.05	Trace	0.001
	B	Nil	60	59.0	0.004	0.06	0.05	Trace	0.012
	C	75	Nil	58.9	Trace	0.04	0.05	Trace	0.013
3	A	Nil	Nil	56.1	Trace	0.02	0.03	0.01	0.001
	B	Nil	60	56.5	Trace	0.04	0.09	0.01	0.013

charge in the cap of the cartridge case, is the element responsible for the impairment of physical properties noted. This fact has been confirmed by obtaining similar results by the addition of antimony to melts of virgin metals. Thus, it is evident that mercury, the other element which has been suspected in the past, is not the cause. This element is also ruled out because of its low boiling point (339° C.), since any traces that had not volatilised on firing the cartridge would be eliminated or considerably reduced in the muffling process, in which the cases are held at a temperature of between 550° and 650° C. for approximately 10 mins.; any final traces would be lost in remelting.

The detrimental influence of the small quantities of antimony introduced is practically confined to the impact values and to the cold-bending and cold-riveting properties. The elongation and tensile strength are very little affected, except in the case of the 62:38 brass, on which the effect of the antimony is greatest. On the other "straight" brasses, the effect is shown to diminish with increasing beta content. The effect on the leaded brasses is similar, although the reduction in impact value is not so great in the higher copper alloy as in the "straight" brass.

The effect on drawn leaded brass is similar to that on the "as extruded" rod, and it is thus concluded that when cases have been used in the mixture, the rods can be safely drawn; the results also indicate that susceptibility to season-cracking is not increased.

Naval brass is the only alloy of those investigated in which the effect of antimony is negligible.

The results of this investigation are summarised concisely by the author as follows:—It has been shown that antimony is the deleterious element introduced into brasses by the use of fired cartridge cases. A marked difference in colour has been observed in the fracture of the alloys made with cartridge cases as compared with those made from usual materials, except in the case of naval brass. This peculiar colour has been reproduced by adding a similar percentage of antimony to an alloy made entirely from virgin metals. Approximately 0.01% antimony is introduced by the use of 60% of fired cartridge cases. No difference has been observed between the effect of clean fired and muffled cases, the percentage of antimony being similar in each case. Results have shown that the use of fired cartridge cases should be avoided in "straight" copper-zinc alpha-beta brasses, especially 62:38 quality, as they have a definite embrittling effect, the properties of resistance to shock and cold riveting being most detrimentally affected. The deleterious effect of the use of cases on the 62:38 brass has been reproduced by adding

antimony to an alloy of the case composition made from virgin metals. From the results obtained, it is estimated that 10–20% of cases can safely be used in leaded brasses with very slight impairment of properties, provided no other antimony-bearing material is used in the mixture. It is similarly estimated that at least 40% can be used in 62 : 37 : 1 naval brasses. A brass rod, conforming to B.S.I. Specification No. 218, made with 30% of cases, has been tested with satisfactory results for the production of fuses, compression test results being equal to the average obtained on rods to this specification. The effect of antimony on cold-drawn 2% leaded brass has been shown to be similar

to its effect on "as extruded" material. It has been indicated that the susceptibility of leaded brasses to season-cracking is not increased by the use of cartridge cases in the mixture. It has been shown that the elongation of leaded brass rods is very drastically reduced by the presence of 0.02–0.10% antimony, introduced by antimonial lead scrap. No detrimental effect of antimony has been noted on the hot-working properties of any of the alloys investigated. No difference in machinability has been observed between leaded brass rods made with and without the addition of cartridge cases to the mixture.

The Effect of Quenching and of Subsequent Prolonged Tempering at 100° or 140°C on Alpha-Base Antimony-Cadmium-Tin Alloys

1.—Changes in Hardness

SOME previous work* on alloys of the antimony-cadmium-tin system has dealt with the stable equilibrium system, a general survey of the mechanical properties of a wide range of tin-rich alloys, and a detailed investigation of the effects of heat-treatment on a group of alloys containing cadmium 3–7%, antimony 1–9%. It was shown that these alloys could be improved by a quenching treatment which suppressed the eutectoid transition $\beta \rightarrow \alpha + \gamma$, and prevented the separation of δ or ϵ from either the α or the β phase. The improvement due to the suppression of the eutectoid transformation was shown to disappear gradually even at ordinary temperatures, but the improvement due to supersaturation of the α or the β phase with respect to δ or ϵ , though of less degree, was maintained for periods up to three years at ordinary temperatures. The greatest permanent improvement was obtained in alloys of the lowest cadmium content then examined (3%), which contained little or no β phase, but consisted chiefly of α with precipitate of ϵ or $\epsilon + \delta$.

The work has now been extended, and a recent investigation reported by Dr. W. T. Pell-Walpole† is confined to α -base alloys containing antimony 4–14, cadmium $\frac{1}{2}$ –10%. In stable equilibrium these alloys all lie within the phase fields α , $\alpha + \delta$, $\alpha + \delta + \epsilon$, and $\alpha + \epsilon$. It has been shown previously that these alloys undergo severe changes in solid solubility during cooling from the solidus to approximately 150°C., and the object of the work described by Dr. Pell-Walpole was to determine whether a useful degree of improvement in mechanical properties could be obtained by suitable quenching treatment, and to see to what extent such improvement would be maintained during prolonged reheating at temperatures of 100° to 140°C. One practical object of this work was to obtain some new, strong tin-base alloys suitable for use as bearing metals which may be required to operate and remain stable in the range of temperatures selected for the tempering tests.

The effect of quenching from the highest practicable temperature, and of subsequent prolonged tempering on 80 α -base alloys has been studied. The alloys have been tested as quenched from 220°, 210° or 200° C. (according to their solidus temperatures), and at convenient intervals during subsequent tempering at 100° or at 140° C. These treatments were extended to 1,000 hours in order to determine the degree of stability of any improvement obtained by the quenching treatment. It is shown that quenching produces marked improvement in alloys containing more than 2% cadmium, or more than 7% antimony.

A maximum value of 44 D.P.H., representing an increase of 45% as compared with the "equilibrium" value, is obtained in compositions containing 5% cadmium, or more, with 8–14% antimony. The behaviour of these quenched alloys during subsequent tempering at 100° or 140° C. is recorded in tables, and typical tempering curves are given.

A group of alloys containing cadmium 0.2%, antimony 8–14%, all undergo temper-hardening at 100° and at 140° C., but alloys of high-cadmium content (i.e., those which harden appreciably on quenching) soften rapidly on tempering at either temperature. In both cases the changes occur more rapidly at 140° than at 100° C. In a provisional explanation of the essential difference between the quench-hardening and the temper-hardening groups of alloys, the author states that in alloys containing less than 1.5% cadmium only one phase, $\text{SbSn}(\delta)$, varies in solubility, and it seems probable that supersaturation of the α -phase with respect to antimony gives an alloy which is soft in the quenched condition, but which may harden on tempering, accompanied by the precipitation of SbSn . In alloys of lower antimony : cadmium ratio, the α is in equilibrium with $\text{CdSb}(\delta)$, or with both SbSn and CdSb together. Supersaturation with respect to CdSb , produced by quenching, appears to be accompanied by severe hardening, while subsequent tempering causes continued softening. The two-stage softening and intermediate hardening observed with certain alloys are probably associated with a combination of the effects attributed to precipitation of SbSn and CdSb , respectively, since both phases are present in these alloys in stable equilibrium.

The maximum hardness obtainable by heat-treatment, i.e., either by quenching alone or by quenching and subsequent tempering, is given in an isoscler map. Increasing cadmium content produces a very rapid increase both in actual hardness values and in susceptibility to improvement by heat-treatment. Antimony content has little effect except in the range antimony 7–11%, cadmium 0–3%. In this area increase of antimony content produces appreciable hardening and increases the response to heat-treatment.

The degree of improvement maintained after 1,000 hours tempering at 100° or 140° C. (subsequent to quenching) is given in tables. It is shown that for service at 100° or 140° C., the composition range antimony 7–14%, cadmium 0–2% maintains a useful degree of improvement. For either temperature the optimum antimony content is 9–11%. Stable hardness values of 33 D.P.H. (after 1,000 hours at 140° C.) or 34 D.P.H. (after 1,000 hours at 100° C.) are obtained, compared with maximum values of 26–30 D.P.H. in the equilibrium condition.

* P. Hanson and W. T. Pell-Walpole, *J. Inst. Metals*, 1937, **61**, 265 and 125.
† *J. Inst. Metals*, 1942, **66**, 329 (October issue).

A Metallurgical Study of German and Italian Aircraft Engine and Airframe Parts

THIS report constitutes a summary of data resulting from the metallurgical examination of German and Italian aircraft engine and airframe parts by the Aero Components Sub-Committee of the Technical Advisory Committee to the Special and Alloy Steel Committee formed for this purpose. In this, the fourth of the series, is presented a summary of investigations on different types of gears, and also some detachable bearings.

The Sub-Committee responsible for these investigations and for this report comprise Mr. W. H. Dyson, Ministry of Aircraft Production; Dr. H. Sutton, Royal Aircraft Establishment; Dr. R. Genders, Superintendent, Technical Applications Metals, Ministry of Supply; Mr. H. Bull, Messrs. Brown-Bayley's Steelworks, Ltd.; Mr. H. H. Burton, The

English Steel Corpn., Ltd.; Mr. W. J. Dawson, Messrs. Hadfield, Ltd.; Dr. W. H. Hatfield, F.R.S., Chairman, Brown-Firth Research Laboratories; Mr. D. A. Oliver, Messrs. Wm. Jessop and Sons, Ltd.; Dr. T. Swinden, the United Steel Companies, Ltd.; and Mr. G. Stanfield, Secretary, Brown-Firth Research Laboratories.

The work included in this report embraces the results of investigations carried out from the beginning of the war until towards the end of 1941, but investigations have continued and are still in progress, and the work is being carried out meticulously. Naturally, no comparisons are made in the report with corresponding parts in British or American aircraft, neither are certain aspects, which the investigations have shown to be open to criticism, emphasised.

Section VIII.—Gears

THIS section deals with the metallurgical examination of 17 gear-wheels from enemy aircraft. Of the total two only are of Italian origin, the remainder being German. The essential data are arranged for ease of comparison in Tables I and II. The compositions used for the various items resolve themselves into four types of steel and the items have, therefore, been tabulated in four groups accordingly.

The dimensions of the various gears are quoted in Table I as approximate sizes only, with a view solely to conveying a general idea of the proportion of each item.

Appearance and Finish

The degree of surface finish on the German specimens was of a very high

order. A generous radius was present at the roots of the teeth and also on the edges at the ends of the teeth. In three examples (Reports 1, 5 and 19b) a shot-blasted finish was noted on areas which were unimportant as regards fitting. In two instances (Nos. 88a and 88b) the web recesses and the roots of the teeth had a smooth blue-black oxidised finish. Elsewhere these gears had a bright finish, suggestive of buffing with emery. The other German gears were generally bright finished all over. One gear (Report 30) was also lacquered in parts. All the tooth faces showed a cross-hatched pattern typical of a ground finish. Figs. 1 to 33 show the appearance of each type.

The standard of finish of the two Italian specimens (Reports 84a and 84b) was appreciably inferior to the German specimens. The side faces, web and tops of the teeth exhibited fine transverse lines left from the machining operation prior to hardening, the whole having a matt appearance. The nature of the surface would not be deleterious to the performance of the gears, but would make the final inspection process more difficult to carry out and introduce risks of masking fine defects.

Marking

All the gears examined were liberally marked with figures and letters for identification purposes. With the exception of one item (5) none of the markings give any indication of a recognisable specification. No 5 was, however, marked EON Mo130, which is probably a standard specification of the D.I.N. series, ECN being the German standards identification for a Cr-Ni case-hardening steel. Two of the wheels were marked with a date, whilst the marking generally appeared to consist of serial numbers and inspector's impressions.

Throughout the items repetition of some of the numbers occurred, but beyond indicating that the marking suggests a common origin for groups of the items no comment is offered on this aspect. The large number of markings present tend to indicate close inspection of quality of the gears throughout processing.

Composition

All the steels used were of the case-hardening types, and may be divided into four main groups:—



Fig. 1.—Sun gear, Fiat A. 80R.C.41.

Fig. 2.—Macrostructure of sun gear, Fiat A. 80R.C.41.

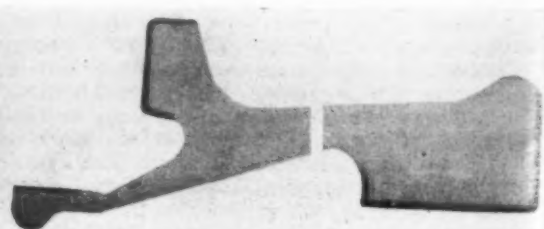


TABLE I.—SUMMARY OF GEAR WHEELS EXAMINED.

Report No.	Type of Engine.	Type of Gear.	Description.	Approximate Size.	No. of Teeth.
84a	Fiat engine A. 80 R.C.41	Sun gear	Teeth cut radially (35 mm. tooth face) on the outside, and teeth also cut in one-half of the bore on the opposite side. Bore partly chambered and eight holes drilled through web. Surface finish inferior to German specimens	13½ in. dia. × 1½ in. wide 2.5 in. min. bore	60
84b	"	Planet gear	Bevel pinion which mates with Item 84a above. Smooth bore. Eight holes drilled through web. Series of small holes connecting root of teeth to bore in eight places	6.4 in. o/d × 1.4 in. tooth face × 2½ in. overall × 2½ in. bore	28
1	Junkers Jumo 211A	Spur gear fitted to crankshaft	Fitted by splines to front end of crankshaft. Evidence of corrosion in the bore. Machined all over. Hollow portion between rim and hub shot-blasted	8½ in. o/d × 2½ in. tooth face × 4 in. dia. bore	40
5	Junkers Jumo 211A	Reduction gear	Machined all over except on hollow surfaces between rim and hub where the surface had a shot-blast finish. Gear splined in bore to fit spline shaft. Design of bore similar to Item 1 above	12½ in. o/d × 2½ in. tooth face × 3½ in. wide overall	62
19a	Mercedes-Benz D.B. 601A	Reduction gear Pinion on forward end of crankshaft	Wheel surfaces smooth finished with emery. Evidence of wear on all teeth and heavy wear near the end of every fourth tooth. Splined in one half of bore. Gear chambered in the bore and generally similar in design to Item 88b	7½ in. o/d × 2½ in. tooth face × 5½ in. wide overall	36
19c	"	Spring drive spur wheel	Consists of a spur gear with a narrow flange and without hub. The flange is bored and slotted in six places to accommodate springs and their fittings	See illustrations Figs. 12 & 13 (No. 2)	54
37	Bramo-Fafnir 323P	Planet gear	Bevel gear with parallel bore fitted with a ball-thrust bearing on one side. Finished smooth all over	5½ in. dia. × 1.4 in. tooth face × 2½ in. overall	25
38	"	Stationary or fixed gear	Bevel gear internally splined over half the length of the bore	7½ in. o/d × 1.4 in. tooth face × 1½ in. wide overall	33
40	"	Driving gear wheel	Teeth cut radially with 1.4 in. tooth face near the outer edge on one side. Bore splined for about half the width on opposite side	11.9 in. o/d × 1½ in. overall × 5½ in. min. bore	54
88a	Mercedes-Benz D.B. 601N	Airscrew reduction gear wheel	Large spur gear chambered in bore and splined both ends of bore. Roots of teeth and hollow areas between rim and hub had very smooth blue-black oxidised finish. Two teeth were broken on the gear when received. (Similar in design to Item 74a)	11.3 in. o/d × 2½ in. tooth face × 3½ in. overall width × 4 in. dia. bore	56
88b	"	Airscrew reduction pinion	Small spur gear. Chambered in bore and splined at one end. Very similar in design to Item 19a. Roots of teeth had black oxidised surface and two teeth showed mechanical damage	7½ in. o/d × 2½ in. tooth face × 5½ in. overall width × 3½ in. dia. bore	36
19b	Mercedes-Benz D.B. 601A	Spring drive pinion wheel	This gear incorporates the starter end. The starter end and small gear wheel had been left as grit-blasted, but those portions within the spring drive 19c had been ground. Bore chambered slightly under the teeth	See illustrations Figs. 12 & 13 (No. 1)	—
74a	Mercedes-Benz D.B. 601A	Airscrew shaft gear wheel	Splined in both ends of bore, web drilled with 12–30 mm. holes. Similar in design to Item 88a	11½ in. o/d × 2½ in. tooth face × 3½ in. overall width × 4 in. dia. bore	56
39	B.M.W. 132K	Super-charger driving sleeve	Flanks of the pinion coated with brass-coloured transparent lacquer and also the whole of the bore. Bore of pinion wheel also coated with a plastic deposit. This item is bored throughout and pinion portion chambered. Connecting sleeve splined	Pinion portion 3½ in. o/d × 1 in. tooth face × 2½ in. bore	31
39	Bramo-Fafnir 323P	Crankshaft coupling gear	Spur wheel splined in bore and fitted in bore with a binding ring. Two holes drilled and tapped in web. Splined in sleeve portion of bore	6.9 in. o/d × ½ in. tooth face × 2½ in. o/a width × 3 in. bore	37
74b	Mercedes-Benz D.B. 601A	Valve and auxiliary drive wheel	This gear has two rows of spur teeth with a row of bevel teeth in between. The bore has a serrated surface and is completely lined with white metal 1 mm. thick, which is anchored in a series of eleven holes through to the bore	6½ in. o/d × 3½ in. teeth bore × 2½ in. o/a width faces { ½ in. ½ in.	60 spur 56 bevel 38 spur
92	Mercedes-Benz D.B. 601N	Rotor shaft and bevel pinion from hydraulic clutch	Consists of bevel pinion integral with shaft and bored for full length	Approximately 3 in. overall dia.	Approx. 13

Italian.

(a) 2½ Ni/0.6% Cr.

German.

(b) 2%Ni/2%Cr, together with 0.2/0.35% Mo in eight of nine steels, also 0.15/0.17 V, with Mo in four steels.

(c) 1.6%Ni/1.6%Cr, with Mo and Mo + V.

(d) 1% Cr/0.25% Mo.

Carbon.—In the German 2/2 type, and also the Italian examples, the carbon content was consistently 0.16/0.18% with one exception at 0.26%, for which

there was no adequate explanation. It was noted, however, that with compositions (c) and (d) the carbon content was higher, as though to make up for deficiency in hardening capacity consequent on reduction of alloy content. The core hardness values of the two items of the 1.6% Ni-Cr composition were lower generally than those of the 2/2 Ni-Cr types, and apart from Ni-Cr content it was noted that the manganese was also lower in the former. The increase in carbon content in the Cr-Mo series was partly reflected in the core hardness values for this group.

Silicon.—With the exception of No. 88 the silicon content for the gears fell

within the range 0.25–0.35. This, combined with the comparative absence of alumina inclusions on micro examination points to a preference for silicon over aluminium as a deoxidant. In the exceptions (Reports 88a and 88b) the silicon was lower (0.18–0.20%) and clusters of alumina were observed on the micro-section, pointing to a different and less satisfactory method of steel-making.

Manganese.—This does not call for comment other than the comparatively low figures in the 1.6% Cr-Ni group. Report 39 in the Cr-Mo group was notably higher at 1.02% than the other three items, but this did not appear

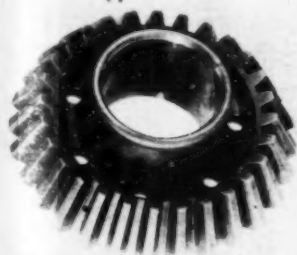


Fig. 2.—Planet gear, Fiat A. 80R.C.41.

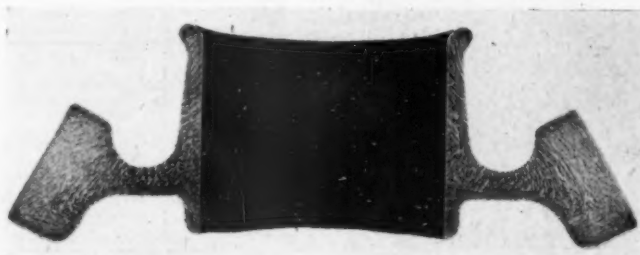


Fig. 4.—Macrostructure of Fiat A. 80R.C. 41 planet gear.



Fig. 5.—Mercedes-Benz D.B. 601A spring drive gear assembly.

to have effected the properties of the gear.

Sulphur and Phosphorus.—The purity of the steels examined was generally of good standard and typical of basic arc electric steel. The exceptions were

Fig. 6.—Macrostructure of Mercedes-Benz D.B. 601A spring drive spur gear.

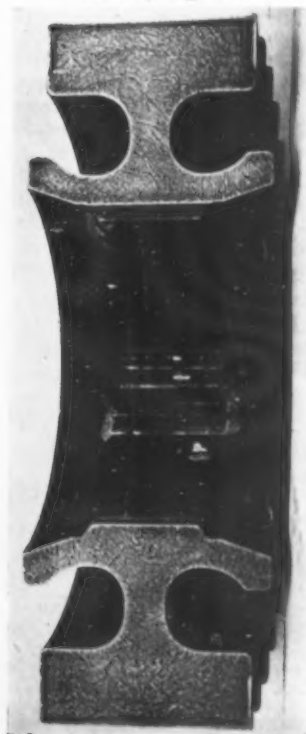


Fig. 7.—Macrostructure of Junkers 211A reduction gear.

Nos. 88a and 88b, where the sulphur was higher (0.022–0.021%), and No. 92 (0.019% S and 0.032% P). There was a tendency for the Cr-Mo group to be less pure than the others. In the three exceptions quoted the effect of the higher sulphur content was duly recorded

TABLE II.—COMPOSITION, GRAIN SIZE, MECHANICAL

Report No.	Type of Engine.	Type of Gear.	Chemical Analysis, %									
			C.	Si.	Mn.	S.	P.	Ni.	Cr.	Mo.	V.	Cu.
84a	Fiat engine, A. 80 R.C.41	Sun gear	0.16	0.26	0.42	0.010	0.007	2.65	0.59	0.06	—	—
84b	"	Planet gear	0.17	0.28	0.51	0.014	0.015	2.80	0.63	0.02	—	—
1	Junkers Jumo 211A	Spur gear fitted to crankshaft	0.18	0.33	0.42	0.018	0.014	2.18	2.18	0.24	—	—
5	Junkers Jumo 211A.	Reduction gear	0.16	0.34	0.48	0.014	0.013	2.08	1.99	0.32	0.17	0.12
19a	Mercedes-Benz D.B. 601A	Reduction gear. Pinion on forward end of crankshaft	0.185	0.25	0.48	0.010	0.013	1.85	2.05	0.24	0.15	0.11
19c	"	Spring drive spur-wheel	—	0.29	0.45	0.010	0.010	2.21	2.08	0.08	0.01	0.12
37	Bravo-Fafnir 323P	Planet gear	0.18	0.32	0.41	0.013	0.012	1.83	2.13	0.35	—	0.05
38	"	Stationary or fixed gear	0.16	0.33	0.49	0.010	0.010	1.97	2.12	0.35	0.16	0.07
40	"	Driving gear wheel	0.17	0.28	0.55	0.013	0.006	1.93	2.10	0.30	0.16	0.08
88a	Mercedes-Benz D.B. 601N	Airscrew reduction gear wheel	0.26	0.18	0.50	0.022	0.015	1.98	1.83	0.27	—	—
88b	"	Airscrew reduction pinion	0.16	0.20	0.42	0.021	0.015	1.98	1.90	0.29	—	—
19b	Mercedes-Benz D.B. 601A	Spring drive pinion wheel	0.20	0.29	0.30	0.010	0.011	1.60	1.59	0.34	0.16	0.17
74a	Mercedes-Benz D.B. 601A	Airscrew shaft gear wheel	0.23	0.30	0.24	0.012	0.008	1.56	1.58	0.32	0.13	—
30	B.M.W. 132K	Super-charger driving sleeve	0.18	0.26	0.87	0.017	0.020	nil	1.04	0.27	—	—
39	Bravo-Fafnir 323P	Crankshaft coupling gear	0.20	0.28	1.02	0.012	0.010	0.30	1.12	0.24	—	0.10
74b	Mercedes-Benz D.B. 601A	Valve and auxiliary drive wheel	0.20	0.26	0.81	0.014	0.013	0.56	1.16	0.26	—	—
92	Mercedes-Benz D.B. 601N	Rotor shaft and bevel pinion from hydraulic clutch	0.23	0.35	0.88	0.019	0.032	0.30	1.22	0.27	—	—

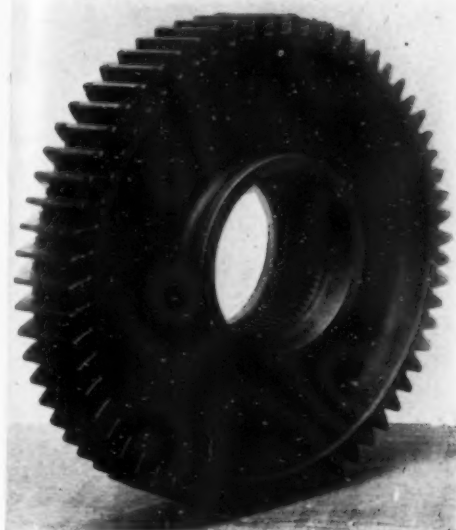
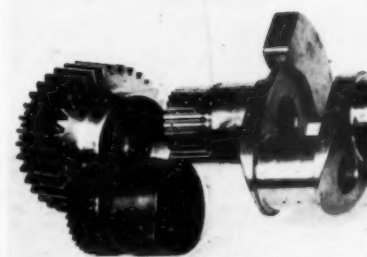
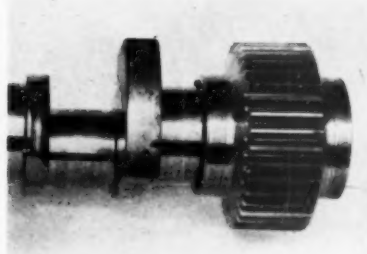


Fig. 8.—Jumo 211A reduction gear.



Figs. 9 and 10.—Mercedes-Benz D.B. 601A reduction gear pinion.

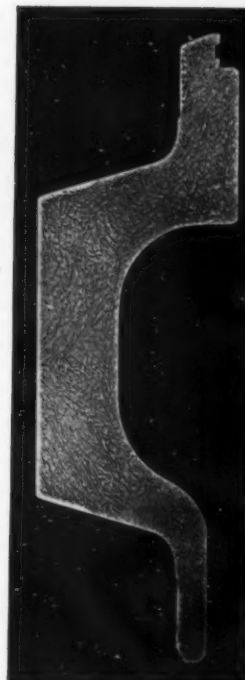


Fig. 11.—Macrostructure of Mercedes-Benz D.B. 601A reduction gear pinion on forward end of crankshaft.

in the micro-examination where sulphide inclusions were observed.

Nickel and Copper.—There was no logical reason for the deliberate inclusion of copper in the various compositions, nor for nickel in the Cr-Mo types in the varying amounts noted. Neither element is deleterious to the steel in the quan-

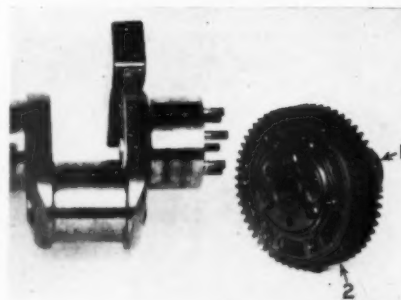
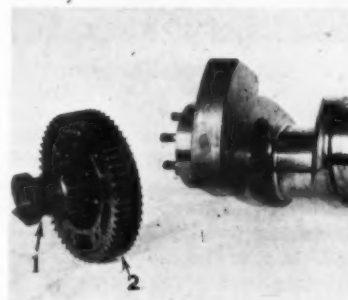
ties observed, but their presence tends to indicate that their inclusion is accidental, and that Germany has her problems with contamination of raw materials.

PROPERTIES AND CASE-HARDENING DATA OF GEAR WHEELS EXAMINED

McQuaid Ehn Grain Size.	Mechanical Properties (Hounsfield Tensometer).						Case-hardening.			
	Position.	0.2% Y.P., Tons/sq. in.	M.S., Tons/sq. in.	EL., %	R.A., %	Equiv. Izod, Ft.-lb.	Position.	Depth.	Hardness (Hd30.)	
									Case.	Core.
1-5	—	—	—	—	—	—	On teeth, splines and other places	In. 0.05	763/774	289/372
1-6	—	—	—	—	—	—	Teeth	0.04	724/752	354/384
7	—	—	—	—	—	—	On teeth only	0.05	743	327
7	Radial Web	51.0	66.8	21.0	63.0	68	On teeth only	0.04 crown	692/747	348/401 (Gen. 390)
	Tang'l	51.0	66.0	20.0	60.0	63		0.02 roots		
6	—	—	—	—	—	—	On teeth and about 1/2 in. externally on each hub	0.05	762/803	421/455
6	—	—	—	—	—	—	On teeth and other wearing surfaces	0.05	798/835	424
6-7	—	—	—	—	—	—	On teeth and in bore	0.06/0.08	702/732	408/436
6	—	—	—	—	—	—	All faces except internal cored face	0.06/0.08	732/752	414/424
6	Tang'l from web	60	72.9	20.0	60.0	—	Chiefly on teeth and splines, thinly elsewhere	0.04	702/732	362/380
1-5	—	—	—	—	—	—	On teeth and thinly on web	0.03/0.04	692/702	396/456
2-5	—	—	—	—	—	—	On teeth and outer surface of sleeve ends	0.04/0.055	732/737	410/434
6	—	—	—	—	—	—	On dogs, teeth and various other places	0.035	848/862	384/401
—	—	—	—	—	—	—	Teeth only	0.06	757/786	366/380
3	Longit from sleeve	67.0	80.0	20.0	58.0	—	Teeth only	0.027	680/763	380/490
6	—	—	—	—	—	—	On teeth only	0.04	672/682	419/434
—	—	—	—	—	—	—	On all teeth	0.04	618/712	434/449
2-3 with some 1	—	—	—	—	—	—	All over except threaded portions	—	766/802	—

Vanadium.—There was no evidence to indicate why vanadium should be present in measurable amounts in six steels out of fifteen. It might on the one hand indicate an individual preference for vanadium inclusion by different steel-makers, or on the other the use of vanadium-bearing raw materials.

Chromium and Nickel.—The amounts present show no abnormal features and



Figs. 12 and 13.—Mercedes-Benz D.B. 601A spring drive pinion (1) and spur (2) wheels.

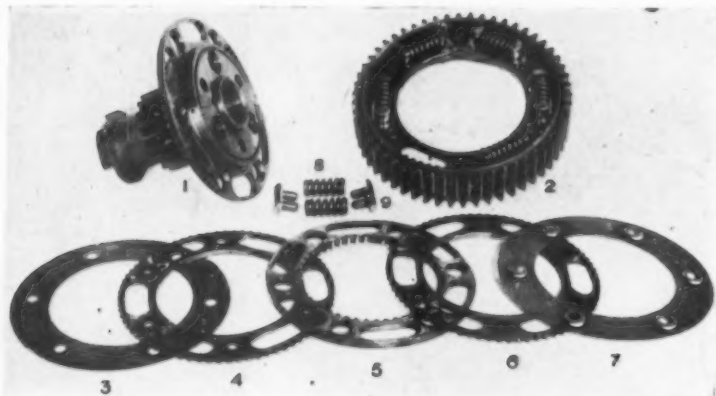


Fig. 14.—Details of Mercedes-Benz D.B. 601A spring drive pinion and spur wheels.

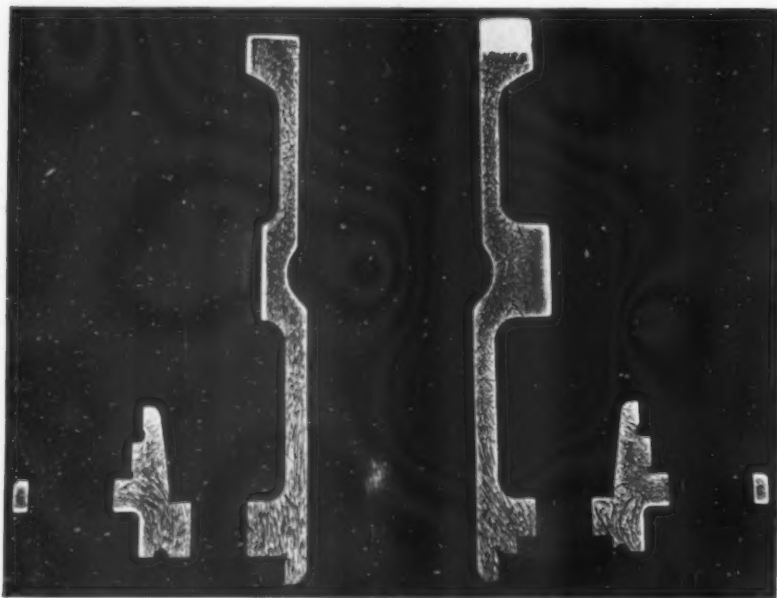


Fig. 15.—Macrostructure of Mercedes-Benz D.B. 601A spring drive pinion wheel.

do not call for special comment. The use of 1.6% Cr, 1.6% Ni in items 19b and 74a seems to be deliberate as distinct from the 2/2 type, and as such is an unusual composition.

Considering the compositions generally, one cannot take any exception to them on the score of irregularity of individual elements. It is to be noted that only one of the German specimens (19c) does not contain molybdenum in

an amount high enough to be considered a deliberate addition.

Macro-Structure, Forging, Etc.

In every instance, macro examination has shown that the gears have been machined from forgings which have been produced in such a manner as to provide the best disposition of the grain

Fig. 17.—Macrostructure of Bramo Fafnir 323P planet gear.

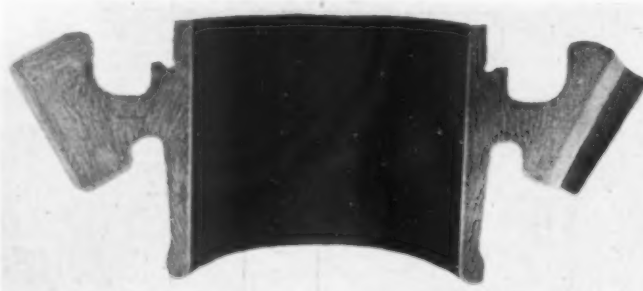


Fig. 16.—Bramo Fafnir 323P planet gear.

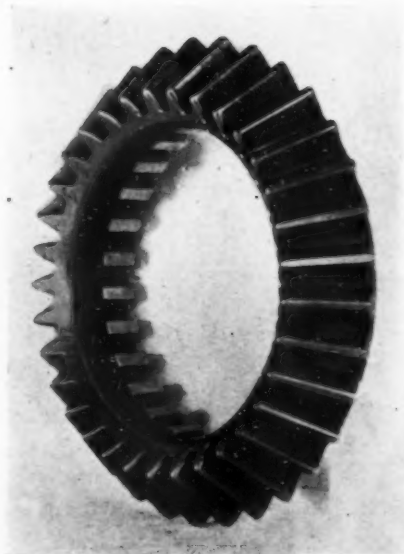


Fig. 18.—Bramo Fafnir 323P stationary or fixed gear.

for maximum resistance to service loading. All the structures showed clear evidence of upset forging and, where possible, the profile of the gear blank appears to have been closely followed in the forging operation.

A number of the gears exhibited a rather pronounced dendritic structure, and the conclusion has been drawn that the amount of reduction of cross-section between the ingot and billet stage has been small. This observation applies particularly to Reports 1, 5, 19a, 19b, 88a and 88b. In other cases the amount of distortion in forging may have masked this effect, but it is fairly safe to conclude that little importance has been attached to large reductions in cross-section at the

Fig. 19.—Macrostructure of Bramo Fafnir 323P stationary gear.



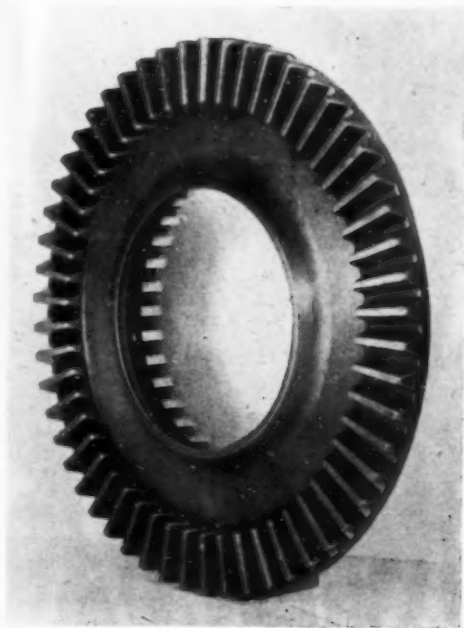


Fig. 20.—Bramo Fafnir 323P driving gear wheel.

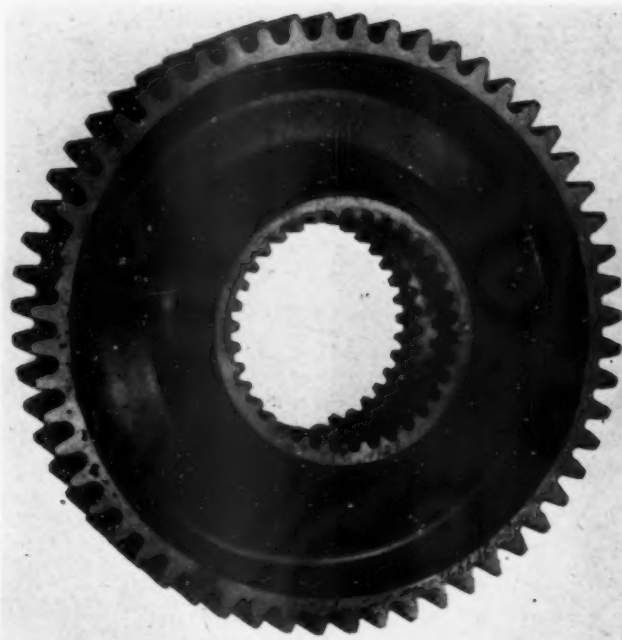


Fig. 22.—Mercedes-Benz D.B. 601N airscrew reduction gear.

ingot stage, but that grain direction has been carefully controlled during the final forging operation.

In the two examples in which the gear was integral with a shaft (Reports 30 and 92) the method has been followed and in the latter the bevel pinion

appeared to have been upset forged on the end of a forged or rolled bar.

Certain of the gears appeared to have been made roughly to shape, followed by the removal of considerable amounts of metal in the later machining operations (Reports 84a, 37, 74b).

McQuaid-Ehn Grain Size

In the 2/2 Ni-Cr group the grain size number is 6 or 7 for all cases but two (Reports 88a and 88b), which are inclined to have a mixed but rather coarse grain size. In view of the remarks made above regarding the lower silicon content and the use of aluminium in the steel of these two items, their grain size

may be considered as additional justification of the conclusion reached that in these two examples the steel-making method was below standard. In the other composition groups the grain size numbers were irregular, and no attempt appeared to have been made towards grain size control. The Italian specimens exhibited very mixed grain size.

Case Carburising and Hardening

The depth of case noted for the different specimens varied widely, the variation being between 0.027 in. and 0.08 in. This depth was, no doubt regulated to some extent by the work to be done by the individual gears, but might also be associated with the amount of material removed from them subsequent to carburising. Regularity of the limiting line of carburising was remarked upon in Report No. 1, and

Fig. 21.—Macro-structure of Bramo Fafnir 323P driving gear wheel.



Fig. 23.—Macrostructure of Mercedes-Benz D.B. 601N airscrew reduction gear.



Fig. 24.—Mercedes-Benz D.B. 601N airscrew reduction pinion.

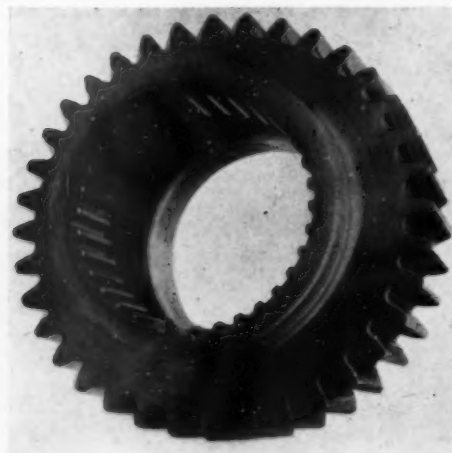




Fig. 25.—Macrostructure of Mercedes-Benz D.B. 601N airscrew reduction pinion

machining after carburising was suggested as likely. In each individual item the carburised zone on the teeth faces was uniform in depth.

In all but a small minority of the gears the micro-examination revealed the presence of carbide nodules near the outer surface of the carburised zone, and some free ferrite in the generally martensitic structure of the core. In two examples (Reports 1 and 5) attention was drawn to the possibility of the refining treatment being omitted at the hardening stage, and it seems likely on the information presented in the reports that after carburising a single-quenching treatment for hardening only is the more usual practice adopted.

Furthermore, it is extremely probable that the gears were lightly tempered up to 200° C. after hardening. This possibility was demonstrated with Report No. 1 by experimental heat-treatment of

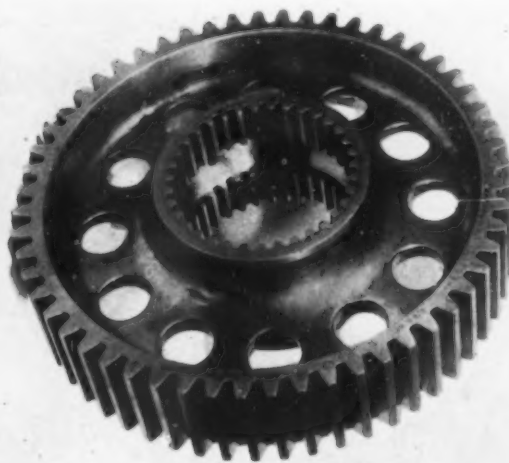


Fig. 26.—Mercedes-Benz D.B. 601A airscrew shaft gear wheel.



Fig. 27.—Macrostructure of Mercedes-Benz D.B. 601A airscrew shaft gear wheel.

a specimen from the gear. Re-quenching this specimen in oil at 760° C. produced a case hardness of 824 V.P.N., as compared with the original 743. The core hardness was as before—i.e., about 327.

Fig. 28.—B.M.W. 132K supercharger driving sleeve.

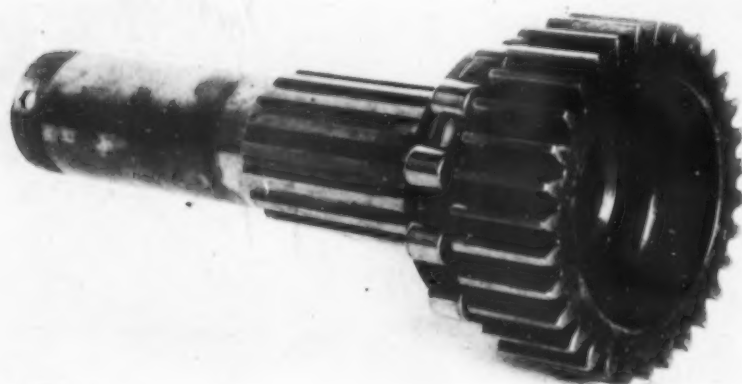


Fig. 30.—Bramo Fafnir 323P crankshaft coupling gear.

On tempering the specimen at 200° C. the case hardness fell to 737.

In only two examples (Reports Nos. 74b and 92) is the absence of free carbide remarked upon, and the absence of free ferrite (Report 92) in one only; and these are in the Cr-Mo group.

Cleanness

Attention has already been drawn to the presence and significance of clusters of alumina in Reports 88a and 88b, and of sulphide particles in these, as well as in item 92. The specimens were generally free from large inclusions and stringers, the longest of the latter, where present, being reported at 0.04 m., and this one was exceptional for the number examined (Report 74b).



Fig. 31.—Macrostructure of Bramo Fafnir 323P crankshaft coupling gear.

In view of the method of forging the gears and the radial deformation produced, "stringers" have not the same significance as in rolled or forged bar, where increase in length is axial. Judged as a whole, however, the German gears examined were clean, and by British Aero-engine steel standards can be regarded as equal in this respect. Only Report 74b stands out as being notably inferior.

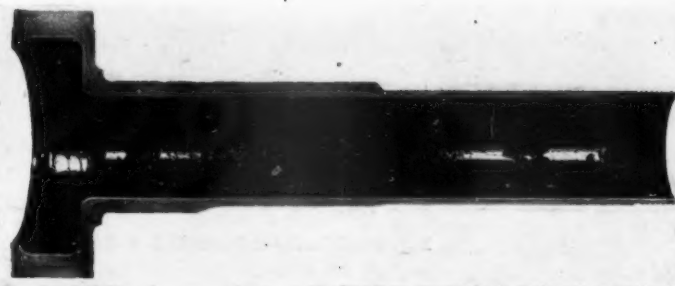


Fig. 29—Macrostructure of B.M.W. 132K supercharger driving sleeve.

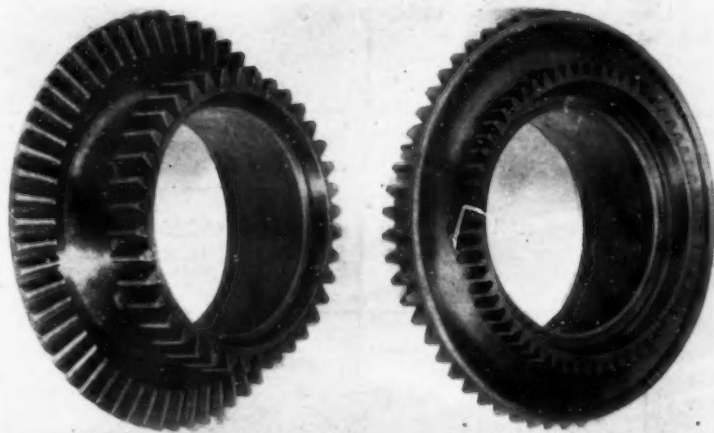


Fig. 32.—Mercedes-Benz D.B. 601A valve and auxiliary drive wheel.

The two Italian gears were reported as below British and German standards, and Report 88a and 88b again came into disfavour as being fairly clean, but below the average.

Mechanical Properties

As the gear dimensions limited test-piece sizes, the only tensile tests available on the gears were made on miniature test-pieces tested in the Hounsfield tensometer. The results obtained were



Fig. 33.—Macrostructure of Mercedes-Benz D.B. 601A valve and auxiliary drive wheel.

Section IX.—Bearings

DURING the course of the investigations of enemy aircraft components a number of detachable bearings and bushes were found to form part of the assembly. The results on the more important of these have been summarised and are briefly discussed below:

1. Crankshaft Bushes

(a) *BMW 132K Engine* (Report No. 28).—A liner with bearing inside the splined end of the shaft (Fig. 6 in Section II* on Crankshafts) was found to consist of a 0.17% carbon steel liner with a cast-on lead-bronze bearing.

(b) *Bramo Fafnir 323P Engine* (Report No. 44).—Two bushes with steel liners were present in this component, one in the front end and the other in the rear half. Figs. 8 and 9 (Section II) show their respective positions in relation to the whole component. The front end bush consisted of a low carbon steel liner with a "cast-on" lead-bronze bearing, while the rear end was a 0.48%

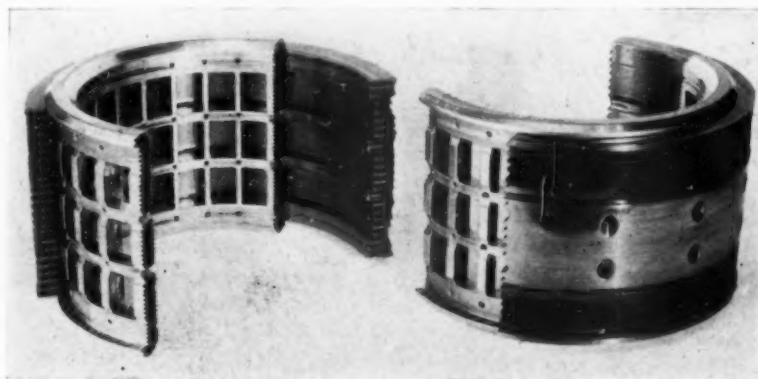
carbon steel liner with a lead rich-antimony-tin white-metal bearing.

(c) *Fiat A80 RC41 Engine* (Report No. 82).—A lead bronze bearing was cast on the inside surface of a 0.17 carbon steel liner.

2. Connecting Rod Bearings and Bushes

(a) *Mercedes-Benz DB601A and DB601N Engines* (Reports Nos. 21 and 87).—Both series of engines contained a roller race bearing at the big end of the

Fig. 1.—Mercedes-Benz D.B. 601N.



* August issue.



Fig. 2.—Mercedes-Benz D.B. 601A.

double rod. These were very similar in design, differing only in minor points. Fig. 1 shows a photograph of one of these in two positions. Both consisted of a steel race in two halves, and were located in position at the big end by four grooves into which fitted the bow bolts of the double big-end rod. The roller-race cage was also in two halves, but was made of a duralumin type of light alloy. The longitudinal edges of the races and cages

The steel parts were all of a similar type of composition—viz., 1% carbon and 1–1.5% chromium. The steel had apparently been hardened and lightly tempered, and was of good quality.

The big end of the single rod of the DB601A engine contained a bush made in two halves, each half being screwed into position by two countersunk screws. The bush was a composite structure, with a 0.12% carbon steel liner if no

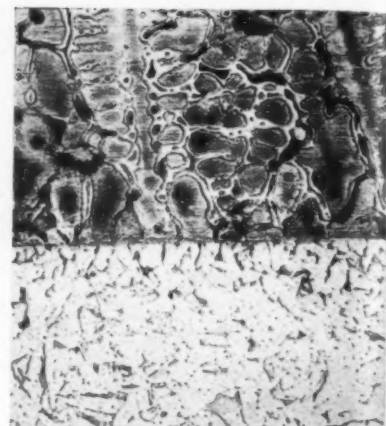


Fig. 3.—Structure at junction of steel and bronze in Mercedes-Benz D.B. 601A. x200.

shows the etched structure at the junction of the steel and bronze.

(b) BMW Engine 132K (Report No.

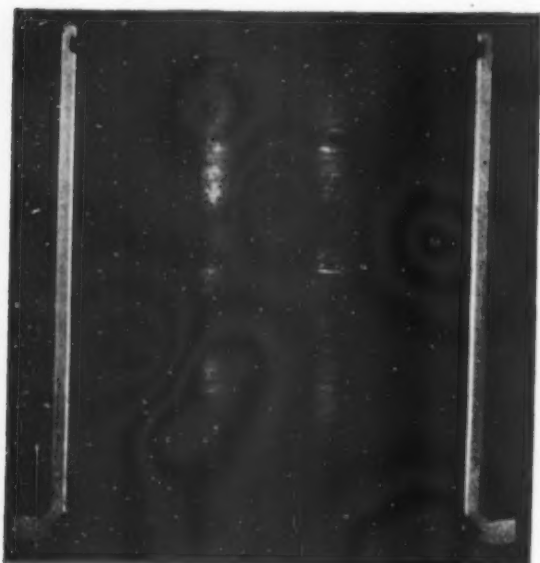


Fig. 4.—Macrostructure of liner of B.M.W. 132K.

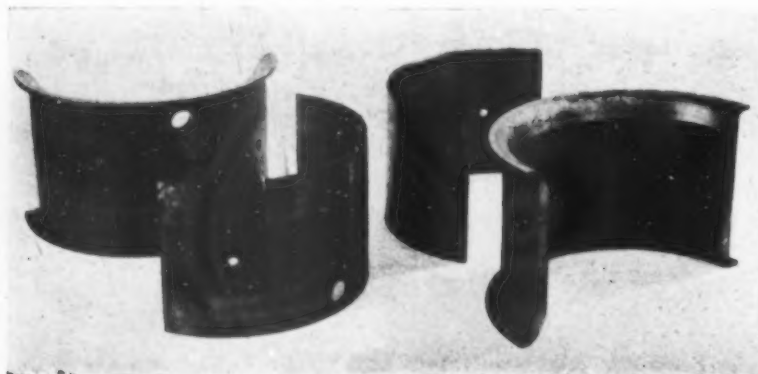
were machined with V-shaped notches, so that the two opposite edges fitted closely into each other and prevented external movement. Several rollers were included in the examination.

special quality and a cast-on lead-bronze lining. Fig. 4a (Section III)† illustrates the bush in position, while Fig. 2 (this section) is a photograph of the bush away from the con rod, while Fig. 3



Fig. 6.—Main bearing of Mercedes-Benz D.B. 601N.

Fig. 5.—Big-end bearing of Junkers 211F.1.



14).—This was a composite inner big-end bush used in the master rod. It consisted of a thin-walled cylinder with oil grooves at the inside top and bottom ends. The construction was similar to some of the other bushes mentioned—viz., mild steel lined with lead bronze. Fig. 4 shows a photograph of a section of the liner.

Junkers Jumo 211 FIE Engine (Report No. 115).—The big-end bearing shown in Fig. 5 consisted of two concentric split cylinders, one of a lead-tin bronze and the other of steel with a lining of lead bronze. The steel shell was a 0.15% carbon steel.

3. Main Bearing from Mercedes-Benz Engine DB 601N. (Report No. 87.)

This was essentially a duralumin alloy forging surrounding a bronze-lined steel bush with a protruding steel pin on each

† September issue.

edge of the light alloy casting (see Fig. 6). The bush was a cheap quality mild steel, 0.12% carbon, on to which a lead-bronze bearing had been cast. The pins were a steel containing 0.46% carbon.

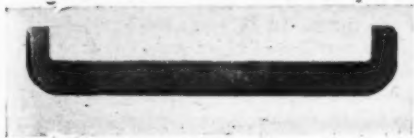


Fig. 7.—Section of liner in main bearing of Mercedes-Benz D.B. 601N.

Fig. 7 shows a section taken through the liner.

4. Miscellaneous

A number of components (engine and airframe) were found to contain ball bearings of various sizes. With only two exceptions the steels were of the carbon-chromium class, containing 1% carbon with chromium varying from 0.5 to 1.5%. The composition of the races was generally at the higher end of the chromium range, while the balls were at the lower end. The exceptions were,

firstly, the ball bearings examined under Report No. 105, which were found to be made from a steel containing 0.42% carbon and 13.4% chromium, and, secondly, a ball thrust bearing examined under Report No. 37, in which the ball was found to contain 1% carbon, 0.87% chromium, 0.30% molybdenum, and 0.26% vanadium.

In the small end of the various connecting rods examined the bushes were in general made from phosphor bronze or pearlitic cast iron. In one instance a copper-nickel-silicon alloy was used.

Season Cracking Test for Brass

In order to effect economies in the use of mercurous nitrate, which is used in solutions to detect stresses in cartridge cases, a procedure is discussed for replenishing these solutions in order to salvage the large amount of mercury left after each test.

THE use of mercurous nitrate solutions to detect excessive stresses in copper-base alloys is almost universal. Until recently mercurous nitrate solutions were used once in the routine season cracking test of cartridge brass and then discarded. Such a procedure required the use of large quantities of mercurous nitrate as well as a fair amount of labour to remove and destroy spent solutions. Increase in the quantities of ordnance materials required, the scarcity of mercury, and the shortage of labour have necessitated certain economies. It is, therefore, of interest to note the description by H. Gieser* of a procedure for replenishing mercurous nitrate solutions so as to salvage the large amount of mercury left after each test.

Preliminary tests showed that 40 to 80% of the mercury remained in a solution which was originally 1% mercurous nitrate after the latter had been used to test brass cartridge cases. Consideration was therefore given to the possibility of replenishing spent solutions.

A stock 10% mercurous nitrate solution was prepared by dissolving 100 gm. of mercurous nitrate ($\text{Hg}_2\text{NO}_3\text{H}_{20}$) in a mixture of 500 ml. of distilled water and 100 ml. of nitric acid (1.42 s.g.) by gentle heating and diluting the solution to 1,000 ml. This 10% mercurous nitrate solution was stored in contact with a small quantity of metallic mercury in order to maintain the mercury ions in the mercurous state, and a 1% mercurous nitrate solution was prepared from this solution by diluting with distilled water. A thiocyanate titration was used to determine mercury in the spent solutions, and values of X corresponding to values of R were obtained from the equation $X = (1 - R) \times 111$, where X represents the volume of 10% mercurous nitrate in ml. to be added per litre of

spent solution to bring the concentration of mercurous nitrate up to 1% and R the ratio of the volume of thiocyanate consumed to titrate the spent solution to the volume of thiocyanate used to titrate the fresh solution.

Mercury cracking tests were run in a routine manner, and the cartridge cases used for such tests were manufactured by a five-draw process, but did not receive a low stress-relieving annealing. The cases were known to produce over 30% external cracks when tested in 1% mercurous nitrate solution. To determine the effect of copper and zinc ions on the mercury, two series of experiments were carried out.

In the first series of tests, sets of 50 unassembled cases were tested in 1% mercurous nitrate solutions containing increasing concentrations of copper and zinc up to 2.5% each of copper nitrate and zinc nitrate. After the test period the solutions were drained off and titrated for fraction of mercury consumed when the results indicated, semi-quantitatively, that the mercury consumed was independent of copper and zinc, up to the concentrations tested.

In the second series of tests, 100 cartridge cases were tested as follows:— (1) 25 cases in 1% mercurous nitrate solution; (2) 25 cases in mercurous nitrate solution obtained by replenishing the spent solution from 1; (3) 25 cases in mercurous nitrate obtained by replenishing the solution from 2; and (4) 25 cases in mercurous nitrate solution containing 2.5% each of copper nitrate and zinc nitrate. The results of the examination for cracks were as follows:—

Experiment No.	No. of Cases Used.	No. of Cases with External Cracks.	No. of Cases with Internal Cracks.
1	25	9	17
2	25	9	23
3	25	11	20
4	25	9	22

These results show that the cracking effect of 1% mercurous nitrate is independent of copper and zinc, at least up to 2.5% concentration of either copper nitrate or zinc nitrate, and that a substantial saving in material, time and labour can be effected by replenishing mercurous nitrate solutions used in routine season cracking tests on brass.

Quality Control of Hollow Steel Blades*

Strength-weight ratio is the most important factor in the design of airplane propellers, but "airworthiness" must also be considered. The demand is for propellers of 10–18 ft. diam., drawn by 800–2,500 h.p. engines.

Hollow steel blades were originally made of laminated sheet. Recently, a solid steel blade—with a unique thin airfoil section resembling a semi-colon, and excess metal bored out of the shank section—has appeared that compares favourably in weight with aluminium-alloy blades.

Modern hollow steel blades are of two types—two-piece blades, and single-piece blades formed from tubes. The two-piece blade uses chromium-vanadium (S.A.E. 6130) steel, which is readily amenable to atomic hydrogen welding. The Lycoming, or tubular, blade is produced from seamless cold-drawn tubes of nickel-chromium-molybdenum (S.A.E. X 4330) steel.

Two major and conflicting requirements affected the choice of steel: (1) high hardenability (sluggish transformation) is necessary, because the blade must be simultaneously quenched and formed in metal discs, and there is an unavoidable delay between the furnace and the press; (2) before forming, the blade must be resistance-welded and copper brazed, and the high hardenability requirement introduces some weld-cracking danger. Actually, in the nickel-chromium-molybdenum used, the carbon is held to 0.31% max. and the manganese to 0.30–0.60%.

*Metals and Alloys 1942, Vol. 16, No. 2, pp. 238–240

*H. P. Reiber. Aviation, 41, 1942, 68–71, 196–179.

The Formation of Hair-Line Cracks

THE experimental work described in this report,* by Professor J. H. Andrew, A. K. Bose, Dr. G. A. Geach and Dr. H. Lee was undertaken at the suggestion of the Hair-Line Crack Sub-Committee with the object of proving or disproving the work of Musatti and Reggiori.¹ The most important feature of their work is that internal defects similar to hair-line cracks were produced by soaking steel specimens in hydrogen at a high temperature followed by rapid cooling.

TABLE I.—STEELS INVESTIGATED.

Steel.	Composition.					Ac ₁ , °C.	Ar ₁ , °C.
	C, %.	Mn, %.	Ni, %.	Cr, %.	Mo, %.		
F1	0.28	0.26	3.13	1.35	0.31	710	420
F4	0.61	0.80	—	—	—	748	680
F5	0.22	0.57	3.8	—	—	700	570

† On cooling from 900° to 350° C. in 2½ hours.

For most of the present work three steels were used. They are described in Table I. Steels F4 and F5 were crucible melts, 50-lb. charges being cast into moulds 3 in. square. Steel F1 was made in a high-frequency furnace, and was obtained in the form of billets 4 in. and 5 in. square from a 3-cwt. cast. These were all forged to 1½ in. round bars. The specimens used were cylinders 4 cm. long and 4 cm. in diameter cut from these bars.

The specimens were heated in hydrogen in a Pythagoras tube closed at one end, the open end being fitted with a water-cooled stopper which carried a long gas inlet tube and a short gas outlet tube. Three specimens were placed near the closed end of the tube, which was heated in a wire-wound tube furnace. Hydrogen was passed into the tube during the heating to 1,200° C., which took about 3 hours, and for the soaking period of 18 hours at that temperature. The hydrogen was then swept from the tube by passing nitrogen for 6 mins., after which the bung was removed and the specimens were at once tipped into cold water, which was stirred during the quenching. Before entering the tube, the gases were passed through alkaline pyrogallol solution and through towers containing calcium chloride and activated alumina.

Before examination, the quenched specimens were aged at room temperature for at least 24 hours. Since the steel F4 could not be cut in the as-quenched condition, tempering was necessary. In order to maintain similar conditions for all three steels, the same tempering treatment was given in all cases except where otherwise specially stated. A transverse slice was cut from the centre of each specimen and one-half was macro-etched in boiling hydrochloric acid to reveal hair-line cracks, whilst micro-sections were prepared from the other half. A second slice, quenched from 800° C., was fractured along a diameter to expose flakes.

The results of the experiments are given together with the summary and conclusions. In the latter the authors state that the results confirm the conclusion of Musatti and Reggiori that internal defects similar to hair-line cracks can be produced in solid steels by soaking in hydrogen at a high temperature followed by rapid cooling through the Ar₁ point. Furthermore, the cracks are not formed immediately after quenching, but an ageing period is required. This suggests that the cracks are not due solely to the stresses resulting from the drastic heat-treatment which the specimens have undergone, and further evidence in support of this view is afforded by the fact that a similar heat-treatment *in vacuo*, or in nitrogen, followed by water-quenching does not cause such defects. It follows, therefore,

that hydrogen must be regarded as the major factor operative in hair-line crack formation.

Certain of the results obtained are in keeping with the hydrogen pressure theory put forward by Bennek, Schenck and Müller.⁹ Thus cracks were never found to develop at a free surface, even at the surface exposed by sectioning a freshly quenched specimen. In all cases the cracks were at least 3 mm. below the surface of the specimen. Again, the fact that no cracks were obtained in cast specimens under the conditions described could be attributed to the open structure of the steel in question.

Whether the hair-line cracks are due to the diffusion of hydrogen into voids or to the breakdown of a hydrogen-rich constituent it is not possible to decide at present. Evidence was obtained, however, that when the cracks had been formed they contained hydrogen. Thus the occurrence of white ferrite veins around the cracks on rapid heating to 300° C. and of globular carbide on heating to 650° C. before sectioning can be explained as follows: During the crack formation at room temperature molecular hydrogen is stored in the cracks. If heating to 300° C. is slow, this hydrogen breaks down to the atomic state, diffuses through the metal and escapes into the surrounding atmosphere. With rapid heating, however, little gas escapes by diffusion, and instead, decarburisation of the metal surrounding the crack occurs with the simultaneous formation of methane, which is unable to diffuse through the metal. As shown in a separate paper,¹⁰ the temperature of maximum stability of methane in contact with steel is 300° C., whilst methane becomes very unstable above 600° C. Accordingly, when the cracks containing methane are heated to 650° C. the methane decomposes with the deposition of carbide along the cracks, while the hydrogen set free diffuses through the metal. Thus, the apparent carbide segregation along the cracks observed in this work as well as by Aichholzer⁶ is the result of crack formation and not the cause.

Some evidence for the existence of a hydrogen-rich constituent was obtained. Thus the gradual disappearance of the white filaments from hydrogen-treated and quenched specimens is in keeping with the suggestion, already made, that these white filaments are a hydrogen-rich constituent which owes its stability, in part, to its hydrogen content.

Although all cracks were obtained by soaking the solid metal in hydrogen, there is no reason to suppose that the mechanism of crack formation is any different from that involved in steelmaking practice. Thus, molten steel may pick up hydrogen and retain it after solidification, and although a steel ingot may contain little or no hydrogen immediately after casting, the possibility of hydrogen contamination during heat-treatment should not be overlooked.

At this stage of the work the authors do not suggest a complete theory of hair-crack formation, but all the results so far obtained are in keeping with the view that hydrogen is the most important single factor involved.

WELDING is proving invaluable in increasing production. It is saving material and labour, and in some cases has multiplied production several times by eliminating bottle-necks in machining capacity. Spot welding in particular is very widely employed for the manufacture of repetition products, and a memorandum on the inspection of spot welds in mild steel, provides a summary of the factors which affect the quality of spot welding, and gives methods for controlling and inspecting spot-welded work. It is Welding Memo. No. 8.

Welding Memoranda are distributed free to contractors and also to Government Departments. Copies may be obtained from the Advisory Service on Welding, Ministry of Supply, Berkeley Court, Glentworth St. London, N.W. 1.

* Paper No. 5/1942 of the Alloy Steels Research Committee (submitted by the Hair-Line Crack Sub-Committee), presented for discussion by the Iron and Steel Institute, Advance copy, Sept., 1942.

1 I. Musatti and M. A. Reggiori. *Revue de Metallurgie, Mémoires*, 1935, vol. 32, p. 531.

2 K. Matsuyama, K. Sasaki and T. Iki. *Tetsu-to-Hagane*, 1938, vol. 24, p. 234.

3 E. Maurer and H. Korschau. *Stahl und Eisen*, 1935, vol. 55, p. 275.

4 H. S. Rawdon. *Transactions of the American Institute of Mining and Metallurgical Engineers*, 1918, vol. 62, p. 546.

5 E. Houdremont and H. Korschau. *Stahl und Eisen*, 1935, vol. 55, p. 297.

6 W. Aichholzer. *Stahl und Eisen*, 1928, vol. 48, p. 1332.

7 E. A. Klausing. *Metallurgy (U.S.S.R.)*, 1937, No. 9-10, p. 79.

8 D. A. Oliver and H. W. Pinder. Unpublished memorandum submitted to the Hair-Line Crack Sub-Committee, Oct., 1940.

9 H. Bennek, H. Schenck and H. Müller. *Stahl und Eisen*, 1935, vol. 55, p. 321.

10 J. H. Andrew, H. Lee and A. G. Quarrell. "The Determination of the Solubility of Hydrogen in Iron and Iron Alloys." The Iron and Steel Institute, 1942, Advance copy.

The Basic Open-Hearth Process To-Day

Part IV.—Pitside Practice, Instruments and Fuel

By W. Geary

In recent years great progress has been made in improving pitside practice, and in this article attention is directed to this important part of steel production. The discussion is concerned mainly with ladles, stoppers and nozzles, teeming speed and temperature, ingot moulds, mould preparation, feeder heads, bottom pouring, instruments, molten steel temperature and fuel, including producer, mixed, and coke-oven gases.

Ladles

Ladle design has received a good deal of attention during the last few years. It has been pointed out in a previous article that enlargement of furnace hearths has been one of the major features of open-hearth development, and, naturally, increases in the capacity of equipment have followed. It is frequently no easy matter to arrange for the larger heats to be accommodated in the ladle, nor is it always possible for increased loads to be handled by the casting crane. Where the casting cranes and runways are able to take heavier loads, the additional weight of the heavier charge can be accommodated by a simple increase in the size of the ladle. The easiest way to increase the ladle capacity is merely to increase its height. This method involves an increase in the ferrostatic pressure tending to multiply teeming troubles, and the usual solution of the problem is to make the ladles oval in shape, thus increasing their capacity without increasing either the height or the trunnion centres.

A very large increase in furnace capacity generally necessitates tapping into two ladles by means of a bifurcated lander. This method has serious limitations, in that it is difficult to regulate the amount of steel going into each ladle. Such regulation is attempted either by arranging the lander in a cradle, so that it may be rotated about its longitudinal axis, or by providing rabblers with which to divert the bulk of the stream to one ladle or the other. Neither method is absolutely reliable.

The majority of increases that are made in the size of heats are not, however, so great as this. Many increases have been made possible by a reduction in the weight of the ladle itself, and of its lining. Many ladles have been redesigned and fabricated by welding instead of riveting, the welded construction including the trunnions and reinforcement members. A properly designed all-welded ladle shows a saving in weight of about one-third in comparison with a riveted ladle.¹ Another possibility of saving weight in the ladle is presented by the brickwork. It has been reported² that careful reduction of the thickness of the lining in those places where least wear takes place increased the ladle capacity about 15 tons, and increased the lining life from 9 to about 13.75 heats.

The bricks used for lining ladles present a constant problem in any basic steelmaking plant. Except in the case of tilting furnaces, it is usually impossible to tap a heat of steel without getting a covering of slag on the ladle. The ladle lining being of an acidic nature, the amount of erosion that occurs depends, principally, on the amount of basic slag that comes in contact with it. A heat of steel coming out of the furnace, due to some accidental variation, light in weight will result in a heavy blanket of slag on the ladle that may easily do as much damage to the ladle lining as four or five normal heats. Attempts have been made to overcome the anachronism of using acidic bricks in contact with basic slag. Plumbago bricks have proved to be exceptionally resistant to slag attack,³ while preliminary experiments have been made with monolithic linings.⁴

Stoppers and Nozzles

Much experimental and research work has been done in the last few years on casting pit refractories, and, indeed, it is at the present time being accelerated. Attention has been given to the desirable qualities of stoppers and nozzles, and a fair measure of agreement exists generally in the trade. Most sleeves have a softening point below the temperature of the molten steel surrounding them, therefore a relatively high refractoriness is desirable. To avoid spalling they should have a high porosity, a uniform expansivity, and a moderately high extensibility. They should be resistant to slag and metal attack, and should have a low-thermal conductivity. Manufacturers have given a good deal of thought and care to this problem of improving the service value of the product, and have used such means as grading and selection of materials, grain-size distribution and specially de-airing. Sleeves must, naturally, be straight and regular in dimensions, with good square ends and undamaged sockets or spigots.

The technique of stopper making varies in different works; for example, some works pack the annular space between the stopper rod and the sleeve with sand, while others leave it empty. The type of stopper-head varies—some works using the bolt-and-cotter type with a fire-clay plug, while others prefer the screwed or the bayonet type. Nowadays much more attention is generally given to the thorough drying of prepared stoppers. Possibly the best type of drying oven which has come to the author's notice is one which is fired by blast-furnace gas, and in which the stoppers are set in an upright position. The body of the oven revolves one notch of a non-return ratchet each time a stopper is inserted, thus making it impossible for a stopper to be taken out of the oven before a predetermined time. A common method which gives good results is to provide a series of steam pipes, alternately with racks, to carry the stoppers. Any method that will ensure the dryness of the assembly is satisfactory, provided a proper time schedule is operated, and stoppers are not taken from the drying room out of turn in an improperly dried condition.

Nozzles, their design and their setting, are matters of importance to all steelmakers. From the refractory point of view it is usually considered that the nozzle should have a slightly lower refractoriness than the stopper-head in order that the latter may make a seat for itself on the nozzle and so ensure a good shut-off. To assist this, graphite heads are used in a number of shops, particularly in America. Where magnesite nozzles are used the stopper-head must, of course, adapt itself to the shape of the nozzle. A number of expedients have been adopted in efforts to improve control of the rate of teeming throughout a cast. Perhaps the best known device is the magnesite ring set in a fire-clay nozzle. The operation of this compound nozzle, and its effect on teeming speeds, was discussed in a paper by A. Jackson in 1931.⁵ He showed that the magnesite ring nozzle was able to control the teeming speed to below 2 mins. per ingot, a time which he regarded as critical for the steel and size of ingot in question. Fig. 1 is reproduced from his paper. In the case of some dead-killed steels the

¹ W. H. Burr. *Iron and Steel Engineer*, 1940, Jan., vol. 17, No. 1.

² I.I.M.M.E. Open-Hearth Proceedings, 1940.

³ Symposium on Steelmaking. *Iron and Steel Institute Special Report*, No. 22.

⁴ Symposium on Steelmaking. *Iron and Steel Institute Special Report*, No. 22, p. 115.

⁵ A. Jackson. *Iron and Steel*, 1931, vol. IV, Feb., No. 5, pp. 167-170.

teeming speed is liable to fall off considerably as the ferrostatic head decreases, and attempts have been made to use a compound nozzle, the bottom half of which is of magnesite of small bore and which may be dropped off, allowing the teeming to be completed through a clay upper half of larger diameter. Another way of doing the same thing is to provide two stoppers with nozzles of varying size, teeming the first part of the heat on one of them and then shutting it off and opening the other.

The conventional fire-clay nozzle almost always cuts out during teeming, the erosion tending to promote streamline flow.⁶ Because such erosion is considered inevitable with the ordinary nozzle, the design of opening is usually very simple, in most cases just a round hole with parallel sides. The design of the opening needs to be seriously considered, however, when steps are taken to minimise the erosion. A leading American open-hearth operator, Mr. C. Fonder-Smith, recently said⁷ that his nozzle opening was oval and tapered towards the bottom, the bottom of the opening being, approximately, 25% larger than at the smallest part, and he was teeming 170 tons heat with very little erosion of the single nozzle.

Nozzles are usually set in the ladle by ramming with a clay-ganister mixture, but some success is reported⁸ with well bricks into which the nozzle fits. The well brick, with some patching, lasts the life of the ladle. Teeming trouble may sometimes be traced to the shape of the nozzle well. With a narrow and deep well the stopper-head, even when raised to the maximum elevation, is still in a stream of steel moving at a high velocity, and if the teemer then tries to provide more freedom for the steel there is a risk of the stopper coming out of the hole. The provision of wide, shallow wells is one of the greatest aids to trouble-free pitside practice.

The high-speed cinematograph has been brought into the realm of teeming practice in the U.S.A. The stream of steel issuing from a nozzle was photographed at 1,500 to 1,600 frames a second and projected back at a rate of about 24 frames a second. One observation that was made from this record was that there was no sign of swirling action on the stream. There can be no doubt that the continued application of such a method will result in increased knowledge of the behaviour of steel during teeming, which will lead to improved design of equipment and hence to closer control of the operation.

Teeming Speed and Temperature

Teeming speed is affected by nozzle size, weight of heat, design of ladle and steel temperature. The desirable speed is determined, usually by experiment in every shop, for each type of steel, and bears a relation to the size of ingot and to the finished product for which it is destined. The best control of teeming speed is afforded by bottom pouring; in conjunction with nozzle size and the altering head of steel, the number of ingots on a plate can be adjusted to maintain a steady rate of rise of steel in each mould throughout the cast. With direct pouring, however, such a nice adjustment is not possible, and the filling rate will vary to some extent. Bottom pouring also eliminates much of the hazard with ingot and bar surface. The effects of splash are always to be reckoned with when pouring is direct. In America pouring is, in general, done through much larger nozzles than in this country. A number of

American operators,² recently discussing nozzle size, indicated that they used nothing smaller than 1½ in. and went up to 2½ in. These were not used for reladling, but for ordinary teeming. Data concerning pit practice submitted⁷ in 1937 by a number of British firms showed clay nozzle sizes for top pouring to vary from ¾ in. to 2 in., and to be mainly in the range 1 in. to 1½ in.

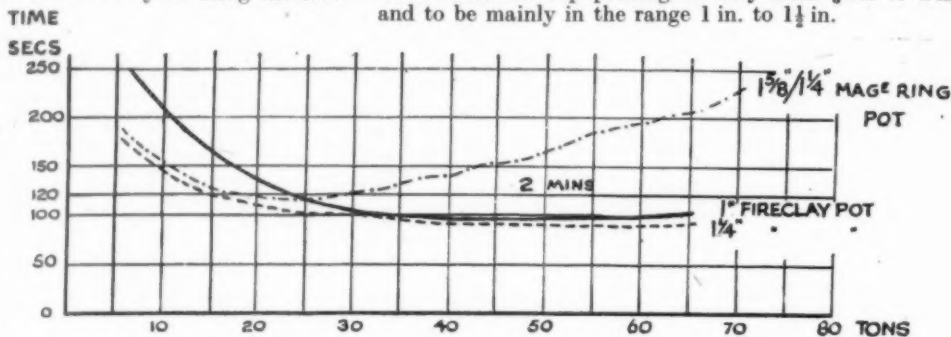


Fig. 1.—Comparison of nozzles—teeming speed tests.

The author inclines to the belief that for many classes of top-poured steel undue emphasis has been laid on the need for very small nozzles. It is agreed that there is a critical teeming rate for a given type of steel and size of mould which, if exceeded, will result in the production of cracked ingots. It is suggested, however, that the stress that has been laid on the importance of slow teeming to avoid cracking may have tended to obscure other factors. Provided the teeming speed is not increased to such an extent as is shown by experience to promote cracking, then a reasonably fast rate of filling a mould will produce a product with a surface more free from the defects caused by splash. Where the rate of rise of metal in a mould is slow, due to bottom teeming, then, of course, there is no risk of splashes of steel appearing on the walls of the mould. But if top pouring is used, then in all ingots of sizes commonly used for the billet trade some splashing will take place. It is believed that the more rapid rise of metal that takes place when faster teeming is employed causes most of these splatters to be washed off and redissolved. In certain specific cases where the main trouble on the inspection banks has been due to effects of splash, decreased rejections have followed the introduction of faster teeming.

Teeming temperature has long been associated with the quality of the ingot. Until very recent years, however, the information that has been available on this subject has been to some extent unreliable, due to the rather unsatisfactory nature of the pyrometers that were available. Certainly the accumulation of results obtained under similar conditions will give in any plant a series of figures upon which a working basis can be devised, but the main difficulty has been the lack of reproducibility of these results under differing conditions. With the development of the Schofield pyrometer, and its successful use in practical conditions in melting shops, this situation has been considerably improved. The behaviour of steel in the ladle with regard to temperature has recently been examined and reported on by T. Land.⁸ An important point demonstrated by this author was that, provided certain elementary precautions were taken, a uniform casting temperature could be obtained. He showed that the uniformity arose because there is liquid metal flowing downwards all round the periphery of the ladle and a column of hot liquid rising in the centre, cooling from the surface being almost entirely prevented by a layer of slag. With such casting uniformity obtainable, and the possibility existing of ascertaining accurately the temperature of the steel in the bath, the way is open for closer thermal control of casting operations.

⁷ Seventh Report on the Heterogeneity of Steel Ingots. Iron and Steel Institute Special Report, No. 16.

⁸ Journal of the Iron and Steel Institute, 1941, No. 2, p. 157 P.

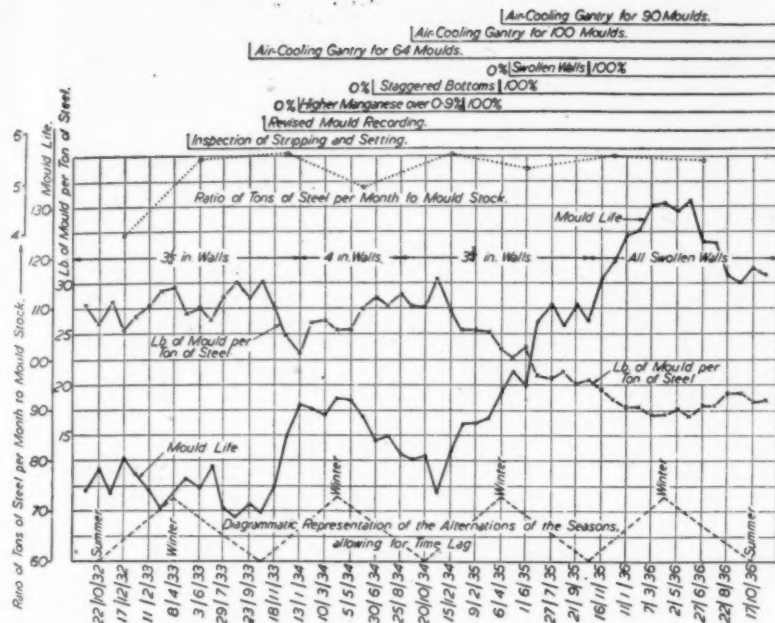


Fig. 2.—The effect of seasonal conditions and improved casting pit technique on mould life (21 in. semi-closed-top moulds).

Ingot Moulds

The design and quality of ingot moulds has in this country been the special care of the Ingot Moulds Sub-Committee, a Joint Sub-Committee of the Heterogeneity of Steel Ingots and Open-Hearth Committees. They have published much information^{7,9} relating to the constitution of ingot moulds, to their method of failure, and particularly to the factors which affect the life of ingot moulds in service. From these studies there have been drawn certain outstanding conclusions which are of importance to all steel makers. Perhaps the most important consideration is that of the temperature of the mould when the steel is poured into it. To cast into a hot mould is the quickest way to shorten its life. This has been known in general terms for a number of years, but the importance of proper rotation, ensuring an adequate cooling time between successive heats, was not completely demonstrated until the publication of the 70th Ingot Report.⁷ Fig. 2, taken from this report, shows results that were obtained in one works by improving the casting pit technique. The principal modifications were the installation of cooling gantries, the redesigning of the mould stool to permit greater air circulation around the moulds, and the swelling of the mould walls with the double object of strengthening the mould and effecting a more rapid dissipation of heat. In the author's own experience, the introduction of a system of rotation, allowing adequate time for moulds to cool between heats, brought about an increase in life of a 3½ tons closed-end mould from 54 heats to 75.

Mould design varies very widely between different works, but certain general principles appear now to be established. A thick-walled mould will fail, in the majority of cases, due to crazing, and the majority of thin-walled moulds will fail by cracking. Experiments have shown that a mould of given design may be altered until approximately half the moulds fail by crazing and half by cracking, and when this point is reached one can be reasonably sure that the optimum wall thickness has been found, and that the minimum consumption of mould metal per ton of ingots will, for the existing pitside conditions, be realised. The life of ingot moulds reported in the 7th Ingot Report⁷ was 53 for closed-bottom moulds and 82 for open-

bottom moulds. Work carried out subsequent to the publication of this report, has undoubtedly resulted in an increase on these figures, as illustrated in the example quoted above. These figures of life vary widely according to the casting technique and the class of steel being made. Naturally, where ingots are being produced for material destined to undergo surface inspection, a mould will be discarded as soon as its surface has deteriorated to the stage at which it would yield an unsuitable ingot. On the other hand, slight ingot blemishes are permissible where the ingot is to receive considerable work in the rolling mills—for example, in the production of structural steel. Many works use a system whereby after a mould has finished its useful life for special steels it completes a further series of heats on a non-surface-inspection product.

The design of moulds has been the subject of considerable experimental work, and most plant operators follow certain well-defined lines, making such modification as their experience dictates. It has been shown, for example, that moulds having a large corner radius are liable to cause

corner cracks in the ingot, and the optimum corner size has been virtually determined at approximately 2½ in. radius. The use of corrugated or fluted moulds has increased in recent years, this development having reached its highest state in the United States. The author believes that for most purposes it is advantageous to use moulds with curved or fluted sides. Fig. 3 illustrates a 3½-ton narrow-end-up mould of this type.

Mould Preparation.—For the production of sound ingots, as free as possible from surface blemishes, some type of

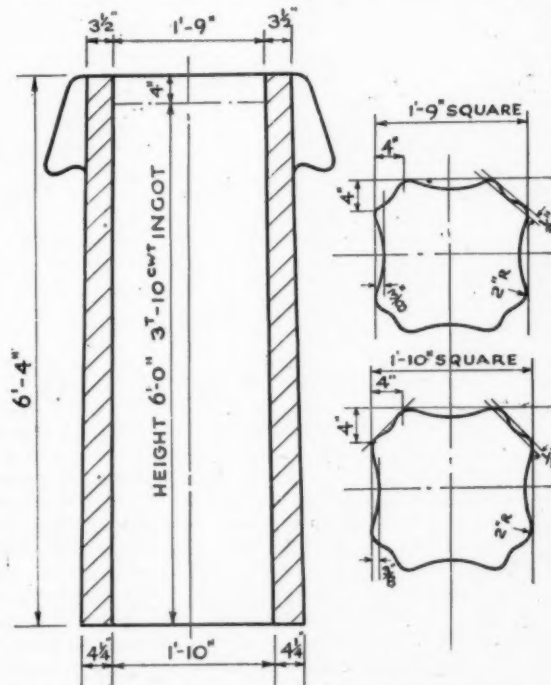


Fig. 3.—A 3½-ton narrow-end-up fluted ingot mould.

mould preparation is essential. A number of materials have been used, each of them designed to produce on the mould surface a coating which will throw off droplets of

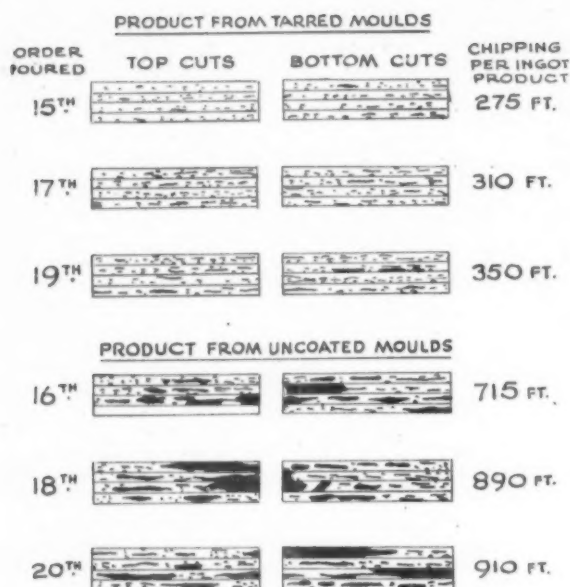


Fig. 4.—Typical billet surfaces produced from tarred and uncoated moulds used for same heat of coarse-grained steel billets pickled and scarfed free from defects.

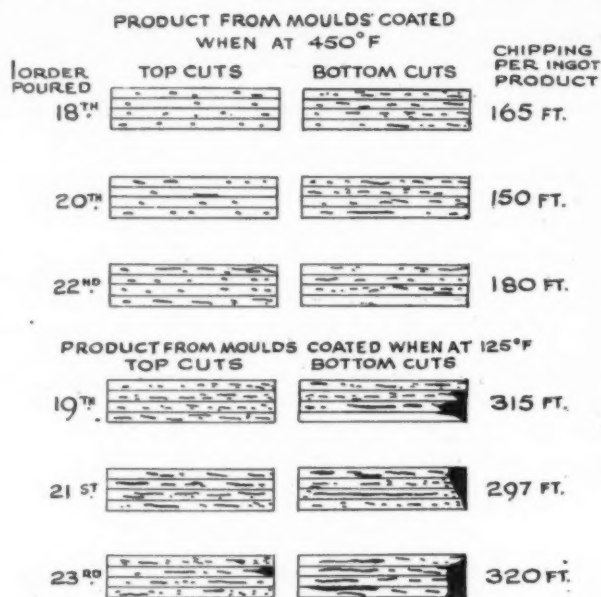


Fig. 5.—Typical billet surfaces produced from moulds which were at 450° F. and 125° F. when coated with tar. All billets from same heat of fine-grained steel.

steel that are splashed on to it and will prevent the steel biting into the mould metal. Among these substances may be mentioned certain proprietary lacquers, salt or graphite, while the latest coating that has been suggested in the literature is sugar, which is said to put a caramel coating on the mould surface. The substance most commonly used is tar, which seems to give generally satisfactory results. It may be brushed on to the mould, but spraying is usually preferred, as the coating so obtained is more uniform. When tar spraying is used it is very important that the mould be within a certain range of temperature when the coating is put on. If the mould is too cold the tar remains in a liquid form and runs down the side of the mould to collect in a pool at the bottom. If the mould is too hot the tar burns off, leaving merely a thin coating of carbon; neither of these moulds will yield a satisfactory ingot. When the mould temperature is in the proper range the tar will dry off and leave a glaze on the surface of the mould which will result in the production of a superior ingot surface. This subject was discussed in a paper read by H. J. Forsythe to the American Open-Hearth Conference in 1941. He shows, quite clearly, the influence of mould-coating practice on the amount of chipping needed on the billets, and his illustrations of these results are here reproduced as Figs. 4 and 5.

Feeder Heads.—The use of feeder-heads, or hot tops, has been common practice for many years, and the modern tendency is for this to increase. The heads in common use fall into three main types, the inserted tile, the superimposed, and the fully floating head. The inserted tile head is generally found in connection with narrow-end-up ingots, and is a compromise that is used where stripping facilities are not available to deal with wide-end-up ingots. The superimposed head is one which is cheap to instal and maintain, but unless it is kept in good condition and carefully used may give rise to hanger cracks in the ingot. The fully floating head, which is adjustable for varying ingot weights, sinks with the contracting ingot and, by keeping the ingot skin in compression, reduces the incidence of hanger cracks. The amount of steel that is put into the head portion of the ingot varies from about 13% to 22%, according to the type of steel being made and the size of the ingot. Recent figures quoted² by one American operator in illustration of the varying percentage put into hot tops were given as 18% for a mould 60 in. high, but 20% to 22% for a mould 120 in. high.

Hot tops are usually assisted in their work by the use of some form of anti-piping compound. These materials may be proprietary compounds which contain a proportion of carbon or other heat-producing substance, or may be simply insulating substances, such as dry powdered coal-ash. Each plant usually works out its own methods, and satisfactory results are reported with various materials of this type.

Bottom Pouring.—There is a definite tendency in the industry, both in this country and abroad, to increase the proportion of bottom-poured steel. Many works use both top and bottom pouring in the same shop, using the latter method for steel requiring superior surface and where a close control of pouring temperature and speed will pay dividends. Undoubtedly, bottom pouring increases the ingot cost, and would, therefore, not be preferred to top casting unless a suitably higher yield of saleable material could be obtained. One objection that used to be raised against bottom pouring was the amount of fluxed runner brick, clay, etc., that was entrained in the ingot. This trouble has been to a considerable extent overcome in recent years; improvements have been made in the chemistry of the refractories rendering them less liable to fluxing, and methods of dry-setting have largely overcome the clay trouble. Redesigning the runners so that dry joints will resist breakouts has been assisted by improving the layout of the bottoms and moulds so that the joints are held in position.

Instruments

The use of control instruments on open-hearth furnaces is being extended in this country, but not at a very rapid rate. The measurement of gas is usual where coke-oven gas or mixed gas is used, and some success has been attained in the measurement of producer gas. Measurement of gas is definitely an advantage to the melter, particularly when the quality remains constant. Gas measurement is usually accompanied by air measurement, for which the installation of a pressure air fan is desirable. A suitable gas-air ratio may then be determined and maintained, either by automatic or by manual regulation, the latter method being generally preferred.

Automatic reversal has not made much headway. Some works have installed semi-automatic reversal equipment, based on the temperature difference in the checkers or flues, and indicated by audible or visible means, but the

majority rely for reversal periods on some form of recording pyrometer. A feeling undoubtedly exists in this country that fully automatic devices take the control of the process too much out of the hands of the melter, because such appliances cannot cope with unusual or unforeseen circumstances.

Draught gauges or recorders are commonly used in the chamber flues or chimney flues. Automatic draught control is not being much used in this country, while in America it appears to be the instrument in most general use.

A few plants in this country have installed pyrometers in the roof. Such an instrument is a valuable aid to the melter, particularly during the early slag-forming period, when heat is being carried on unfluxed lime. In the U.S.A. installations exist in which the fuel supply is automatically reduced by a relay from the roof pyrometer when the temperature of the roof reaches a predetermined figure. So far as the author is aware this additional refinement is not being used in this country.

The papers in the Symposium on Steelmaking give details of the instruments used on many British plants, but the foregoing brief comments show that the instrumentation of British furnaces is far from being complete. For the sake of comparison some figures concerning the instrumentation of American furnaces are given below. They were reported by W. C. Buell,¹⁰ and are taken from the replies to a questionnaire circulated to American open-hearth plants. Of the operators reporting:—

88% used draught control.
62% used some form of reversing device or reversing indicator
31% used roof temperature control.
23% used fuel/air ratio devices.

As to the relative value of control to operators:—

56% cited draught control as the most valuable.
18% cited reversing control as the most valuable.
6% cited roof temperature control as the most valuable.
12% cited fuel/air ratio control as the most valuable.

Due to the greater use of control instruments in America, one learns of more results and hears of more opinion. The latter are by no means always favourable; it is clearly impossible for an operator to install a control device and be sure of getting a satisfactory return on the outlay. The author holds the opinion that instrumentation will increase. It is quite likely that the larger of our furnaces, engaged on the production of tonnage steels, will become very fully equipped within a reasonable time. The reason we are behind the Americans in this particular is probably due to the fact that until comparatively recent years most of our furnaces were fired with producer gas, often from a common main, while many of theirs were fired by oil. Until recently, therefore, we could only guess at the amount of gas an individual furnace was using, and it was, therefore, impossible to determine whether a new control installation operated to give an improved fuel consumption or not, and thus a most important factor in the results was not available.

One most important point in the use of control or recording instruments is their maintenance. The conditions in and around a melting shop are not helpful to the working of scientific instruments, and to keep them in continual good order constant attention is needed. The melter has long ceased to regard a new "clock" on his furnace as a chemist's toy; he is anxious to know what it does, and how it can help him in his work; he learns to use it, and then to rely on it; but woe betide it if it lets him down. He never has the same confidence in it again, nor has he the same faith in any other device that is offered him. For this reason, therefore, the author believes that any attempt to increase instrumentation is foredoomed to failure, unless an operator is prepared to pay not only for the instrument itself but also for really adequate continuous maintenance of it.

(To be continued.)

Rate of Oxidation of Typical Non-Ferrous Metals

IN a previous paper* D. J. McAdam, jun., and G. W. Geil gave results of an investigation of the rate of formation of oxide films on steel at elevated temperatures. The thickness of these films was determined by means of interference colours, sometimes called temper colours or "heat" colours. These colours are caused by interference between rays of light reflected from the inner and outer surfaces of the oxide film. The coincidence of two waves differing in phase by 180° causes light of a certain wave-length to disappear: if the incident light is heterogeneous, therefore, the reflected light is of the corresponding complementary colour. Interference occurs when the film thickness is an odd multiple of one-fourth the wave-length of a component of the incident light. Interference, however, is determined by the wave-length in the film, not by the wave-length in the air. The index of refraction of the oxide, therefore, is a factor involved in the relations between wave-length, film thickness, and interference colour. A knowledge of the wave-length of the light in the oxide film, corresponding to an interference colour, would make it possible to estimate the film thickness.

By means of interference colours caused by oxide films, a study has been made of the rate of oxidation of typical non-ferrous metals, as affected by composition, temperature, oxidation time, and film thickness, and the results are reported in a more recent paper by the same authors.† As in their previous paper, the authors present two-dimensional diagrams of three types as complementary views of three-dimensional diagrams, each showing the relation between temperature, oxidation time, and film thickness.

The materials studied included electrolytic copper, lead and zinc; aluminium of about 99.9% purity, and nickel of the commercial A grade; ruthenium and rhodium, 99.99% pure; cadmium, chromium, cobalt, manganese, niobium, silicon, tantalum, tungsten, vanadium and zirconium. With eight of these metals complete diagrams were obtained; with seven metals the approximate forms and positions of the graphs were obtained for interference colours of the first order; with three metals only the approximate positions of the graphs were obtained. A comparison is made between the results obtained with these metals and with typical steels.

For a constant film thickness the relation between temperature and oxidation time is linear when plotted with logarithmic co-ordinates. The variation of the film thickness either with time at constant temperature or with temperature for constant oxidation time, when plotted with logarithmic co-ordinates, is represented by a reversed curve. When plotted with Cartesian co-ordinates, the variation of film thickness with time at constant temperature is represented by a curve without reversal; this is a complex curve, becoming approximately parabolic at the upper end.

The authors attempt to correlate the forms and positions of the curves with the affinities of the metals for oxygen, with the resistances at the metal-oxide interface, and with the resistivity of the oxide film. The variation of the rate of oxidation with the film thickness is such that it may be expressed in terms of an assumed variation of the resistivity with the film thickness. This means merely that the film behaves as if its resistivity (not necessarily its electrical resistance) varies in the manner described.

* "Rate of Oxidation of Steels as Determined from Interference Colours of Oxide Films." *Jour. Research NBS*, 23, 63-124 (1939) RP 1221.

† "Rate of Oxidation of Typical Non-Ferrous Metals as Determined by Interference Colours of Oxide Films." *Jour. Research NBS*, 28, 593-635 (1942) RP 1470.

Hardness Testing of Heat-Treated Forgings

By Bernard Thomas, F.Inst.P., F.Inst.F.

The variety of means available for hardness testing of heat-treated forgings leads frequently to difficulties in satisfying specification requirements. The subject is discussed, and tests are described which have been carried out on forgings of various weights in order to establish some ruling likely to be helpful in overcoming these difficulties.

IN the hardening and tempering of drop-forgings of any importance it is the usual procedure to have a covering test-piece, either with each batch heat-treated, or covering the consignment or cast of steel as the case may be. While from such test-pieces may be determined the physical properties, such can relate only to the actual piece tested, and though acting as a rough guide to the probable condition of the forgings covered, cannot really be accepted as a sinecure that all forgings have similar characteristics. Where test-pieces may differ in ruling thickness to the work, or where the latter may have exaggerated thick and thin parts, the possibility of discrepancy becomes increased. As a necessary safeguard, therefore, the actual forgings are hardness tested. Unfortunately, however, the variety of means available for this work leads frequently to incorrect usage, and the object of these remarks is to discuss the subject.

There are various methods of testing hardness available in machine form, including Brinell, Rockwell, pyramid, diamond and scleroscope. Of these, the first three named are the most generally used on drop-forgings.

While it is unnecessary to describe here the Brinell method, it should be emphasized that for ferrous metals the load and ball used should always conform to the ratio of $\frac{P}{D^2}$ equals 30, where P equals pressure and D equals ball diameter. This is as specified by the British Standards Institution. Table I shows the ball diameter applicable for various standard loadings.

Loading in Kg.	Ball Diameter.
3,000	10 mm.
750	5 "
120	2 "
30	1 "

The Rockwell hardness tester, and other direct reading machines, differ from the Brinell in that the depth of the impression is measured and not the diameter. Of the various combinations of loading and penetrators available, the two most used are, firstly, Scale C, for hardened steel, employing a conical diamond and 150 kg. load; and secondly, Scale B, for unhardened steel, or that of low temper, using a $\frac{1}{16}$ in. diameter ball and 100 kg. load.

Machines suitable for diamond pyramid testing may use in addition, if required, a small steel ball for the softer materials at various loads between 10 kg. and 120 kg. Where such is employed with the above machines, Brinell conditions apply in accordance with B.S. Spec. 240. The diamond pyramid is the standard 136° four-sided diamond indenter and should be operated in accordance with B.S. Spec. 427. Standard loadings are 120 kg. and 30 kg. for medium hard and hardest steels, and 10 kg. for either thin sheet down to 0.1 mm. in thickness and case-hardened components.

Thus, briefly described, are the normal everyday methods employed for the hardness testing of forgings. Experience is obviously required to guide as to method to be employed in specific cases, but it is generally assumed that the largest loading and penetrator be used wherever possible. There must, of course, be always adequate mass of metal sur-

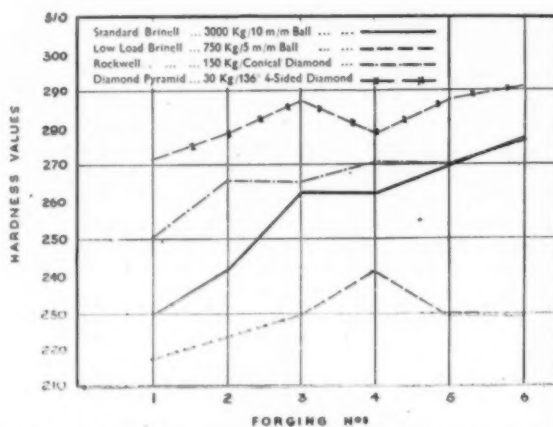


Fig. 1.—Comparison of hardness readings on 1 1/2 lb. forgings.

rounding the indentation to prevent "spreading" under load and giving a false value, and to meet this requirement there should be at least ten times the depth of the impression in the thickness of the material under test, and the centre of the impression should not be less than $2\frac{1}{2}$ times the diameter of the impression from any edge.

Probably the most commonly used of all types in the testing of drop-forgings is the Brinell, with a 3,000 kg. loading on a 10 mm. diameter steel ball. The limitations of this machine, however, are met when either the mass of material is too small to meet the condition already outlined, or where the hardness approaches, or exceeds, 500 Brinell hardness numeral. The first-named limitation can be met by reducing the load to 750 kg. and employing a 5 mm. ball, but to meet the latter it is more usual to use another type of machine employing a diamond indenter. Discrepancies are being met, however, in cases where one person passes out a batch of forgings on one type of machine and the consignee fails to agree when using a different method.

At first sight it might be assumed that there should be no discrepancy when all machines conform to certain accepted standards, but the reasons for this are described in the following. Forgings during production may be heavily scaled and/or decarburised, and following subsequent heat-treatment the outer skin or layer fails to respond as does the interior. Whereas a heavy load of 3,000 kg. may be calculated to break through this layer and give a satisfactory hardness figure, one of lower weight has less possibility of success. That a ground surface is prepared to receive the impression is not always sufficient to ensure satisfactory condition. Beyond this, many specifications entail quenching after tempering as a necessity to maintain Izod impact values, and with certain analysis materials, such as those of nickel-chromium-molybdenum contents, a "skin" hardness is frequently acquired by this quench, particularly on small size work, which renders readings false on low-loading type machines.

Having met such difficulties several times of late, the writer determined to carry out a few tests on forgings of various weights in order to establish some ruling which might be helpful to others.

The first case examined was a small, flat forging, 1½ lb. in weight in specification 4S11, and having a ruling thickness of ½ in. Taking the 3,000 kg./10 mm. ball Brinell as the "standard" test, six forgings were chosen having a roughly ascending order of hardness. Three readings were taken on each separate forging, the mean being adopted as

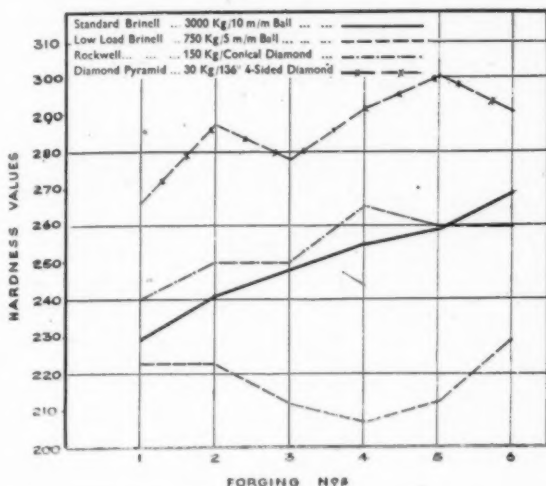


Fig. 2.—Comparison of hardness readings on 2 lb. forgings.

the true hardness. The same six forgings were subsequently hardness tested by other means as in Table II.

TABLE II.—METHODS OF HARDNESS TESTING EMPLOYED.

A.	Standard test.....	Brinell	with 3,000 kg. load/10 mm. ball
B.	Subsequent test.....	Brinell	750 kg. load/5 mm. ball.
C.	"	Rockwell	150 kg. load/conical diamond.
D.	"	Hardometer	30 kg. load/136° 4-sided diamond.

In Table III are given the hardness readings obtained by the four separate methods. In each case the range of hardness found from the three impressions is quoted, together with the mean in bolder type. The means are subsequently employed in Fig. 1, to show more graphically the full extent of the variation between the different methods.

TABLE III.—HARDNESS READINGS ON 1½ LB. FORGING IN 4S11 AFTER HEAT-TREATMENT.

Forging No.	A Method.		B Method.		C Method.		D Method.	
	Range.	Mean.	Range.	Mean.	Range.	Mean.	Range.	Mean.
1	229-229	229	212-223	217	240-255	250	263-287	271
2	235-248	241	217-229	223	255-290	265	263-301	278
3	255-269	262	235-248	241	260-270	265	275-301	287
4	255-269	262	223-235	229	260-276	270	263-301	278
5	269-269	269	229-229	229	260-270	265	263-287	287
6	269-265	277	229-229	229	276-283	276	287-301	291
Average Range Variation:	10		8		16		27	

Key to lettered methods in Table II.

The next example chosen had the same ruling thickness of ½ in. as in Table III, but a greater area, which gave it the increased weight of 2 lb. Table IV portrays the hardness readings obtained following similar procedure as previously outlined. Diagram corresponding is shown in Fig. 2.

The third example was a forging of the "lumpy" type, having a ruling thickness of ¾ in. and weight of 18 lb. Again following the same methods, the results are tabulated in Table V (Fig. 3).

TABLE IV.—HARDNESS READINGS ON 2 LB. FORGING IN SPEC. 4S11, HEAT-TREATED.

Forging No.	A Method.		B Method.		C Method.		D Method.	
	Range.	Mean.	Range.	Mean.	Range.	Mean.	Range.	Mean.
1	223-235	229	217-229	223	235-245	240	252-275	266
2	229-255	241	217-229	223	245-250	250	287-287	287
3	241-255	248	207-217	212	240-255	250	275-287	278
4	255-255	255	197-217	207	255-276	265	275-315	291
5	255-269	259	207-217	212	250-270	260	301-301	301
6	269-269	269	223-235	229	250-270	260	275-301	291
Average Range Variation:	11		13		15		17	

Key to lettered Methods in Table II.

The fourth and last example was one of softer character, in order that the Rockwell machine might test on lower load and steel ball, and a steel ball be also substituted for diamond in the diamond pyramid tester. Accordingly, therefore, the four methods employed in the last group were as in Table VI. The forging was large in surface area, had ruling thickness of ¾ in. and a weight of 10 lb. (Fig. 4).

TABLE V.—HARDNESS READINGS ON 18 LB. FORGING IN SPEC. S. 69 HEAT-TREATED.

Forging No.	A Method.		B Method.		C Method.		D Method.	
	Range.	Mean.	Range.	Mean.	Range.	Mean.	Range.	Mean.
1	235-241	241	229-248	241	235-250	240	233-259	243
2	241-241	241	229-229	229	270-290	283	333-287	323
3	248-255	248	241-248	241	265-305	276	214-263	238
4	248-255	255	235-248	241	240-270	260	242-275	255
5	248-277	262	229-248	241	250-301	276	275-287	278
6	269-269	269	255-255	255	278-293	285	223-275	255
Average Range Variation:	8		10		29		35	

Key to lettered methods in Table II.

In reviewing the results tabulated, an additional feature is made by provision of the average of the variations found in the hardness ranges. From these it will be seen most clearly that variation increases as the loading lessens; the Brinell methods using 3,000 kg. and 750 kg. loads respectively, having least variation, whilst the methods employing 150 kg. and 30 kg. have considerably more. Beyond this, however, the variations increase with weight of forging until those found in Table V, in the case of one of 18 lb., reach a serious extent. Conversely, Table VII shows least variations, as might be expected under the circumstances, in view of the relatively low hardness values of the softer material covered.

TABLE VI.—METHOD OF HARDNESS TESTING EMPLOYED ON FORGINGS IN TABLE VII.

A.	Standard test.....	Brinell	with 3,000 kg. load/10 mm. ball.
B.	Subsequent test.....	Brinell	750 kg. load/5 mm. ball.
C.	"	Rockwell	100 kg. load/¼ mm. diam. steel ball.
D.	"	Hardometer	30 kg. load/1 mm. steel ball.

TABLE VII.—HARDNESS READINGS ON 10 LB. FORGING IN SPEC. EN. 8 HEAT-TREATED.

Forging No.	A Method.		B Method.		C Method.		D Method.	
	Range.	Mean.	Range.	Mean.	Range.	Mean.	Range.	Mean.
1	187-197	187	156-156	156	200-216	205	187-207	197
2	197-197	197	149-156	156	205-216	210	179-183	179
3	187-197	197	163-170	170	205-222	216	207-217	207
4	197-203	207	163-170	170	222-228	225	187-207	197
Average Range Variation:	7		5		12		1	

Key to lettered methods in Table VI.

Apart from the question of averages, further study of the tables shows that peak differences up to 51 hardness value occur between high and low readings on the same forging, where machines of low-loading capacity are employed. Such differences suggest that no one reading could therefore be taken as representative of any given forging, and consequently the machines are not wholly suited for the work.

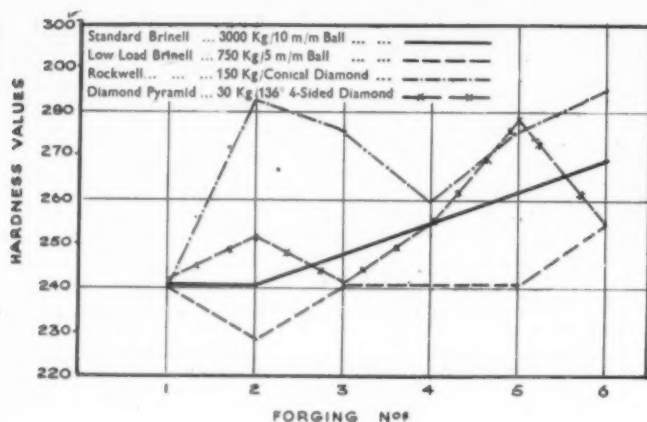


Fig. 3.—Comparison of hardness readings on 18 lb. forgings.

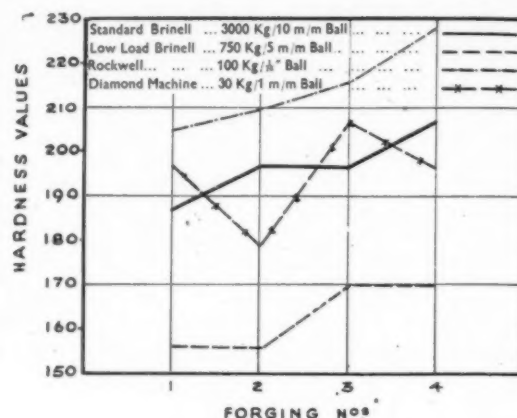


Fig. 4.—Comparison of hardness readings on 10 lb. forgings.

Beyond the foregoing, the diagrams illustrating the tables show that the lower loading machines tend to yield higher average figures than the "standard" hardness as determined by the 3,000 kg. load Brinell. While it is accepted that a diamond indenter yields possibly a truer return up to a certain degree in the case of hard steel, the difference as laid down in the A.I.D. Inspection Instruction No. M406 (Issue No. 2) amounts only to 11 at 300, whereas the difference found in tests explored is nearer 40.

In further explanation of the diagrams, it may be said that the Brinell at 3,000 kg. loading is shown as a heavy solid line as the "standard," coupling together the plotted means of the six forgings examined. The remaining three methods of testing are clearly indicated.

One surprising feature is the low comparison of readings obtained throughout with the 5 mm. ball Brinell. The loading was naturally checked for calibration and found correct against check test block, and yet on actual forgings a series of low average results were forthcoming for which

no explanation is offered.

Summarising the position, it should be stated quite clearly that no reflection is intended against the accuracy of machines of low loading capacity, but that they are out of their sphere in the testing of rough forgings of any fair weight.

Secondly, if such machines are the only ones available for hardness testing, no one reading should be assumed as representative of the forging but a mean of at least three should be obtained.

Thirdly, consignor and consignee should have some agreed arrangement regarding use of similar testing methods, but where same differs from "standard" such differences should be dealt with on the basis of comparator tests.

Lastly, to avoid confusion, whenever hardness figures are quoted, same should always be qualified by the method obtained, and not left baldly to give rise to the possibility of controversy.

Relaxation Resistance of Nickel-Alloy Springs

As a result of a series of tests, stresses required to produce 2, 4 and 6% load stress, or relaxation, in coil springs held at constant height and constant temperature, have been determined by B. B. Betty, E. C. MacQueen, and Carl Rolle for several alloys—namely, Monel, "K" Monel, "Z" nickel and Inconel. Successive test temperatures from 150° to 370° C. were used. The range of temperature over which these several alloys can be used successfully, when load loss is a criterion, has been determined. "K" Monel, "Z" nickel, and Inconel have been found to be comparable in this respect to high-alloy spring steels, while Monel is more nearly comparable with low-alloy steels.

Inasmuch as the high-nickel alloys retain their strength to a considerable degree at elevated temperatures and resist oxidation and corrosion as well, they have been useful in many elevated temperature spring applications. Unfortunately, quantitative data have been lacking on the extent to which coil springs of these materials would retain their load-carrying capacities. As a result of this situation and in co-operation with the American Society of Mechanical Engineers' Special Research Committee on Mechanical Springs, the authors have undertaken to supply accurate laboratory data for Monel, "K" Monel, "Z" nickel, and Inconel.

The tests were reported in a paper contributed by the Special Research Committee on mechanical springs at the annual meeting of the above Society in December last year,

and are reproduced in *Monel Notes*—26. Compiled in the accompanying table are the stresses required to produce 2, 4 and 6% relaxation in the seven-day testing period, as obtained from the curves developed from the results of tests which are published with the paper.

It will be noted that Inconel resists relaxation up to high temperatures, and may be used at high stresses up to 345° C. Above this temperature the stress must be lowered considerably and a slight degree of relaxation must be tolerated; "Z" nickel and "K" Monel will withstand higher stresses than Inconel at the lower temperatures, consistent with their generally higher level of mechanical properties. "Z" nickel may be used with high stress at temperatures up to 290° C. and with reduced stress up to 315° C. "K" Monel may be used with high stress up to 230° C. and with reduced stress up to 260° C. Where other factors, such as corrosion resistance, are involved, Monel offers possibilities as a spring material for temperatures up to about 205° C. and at moderate stress levels. Monel springs should be stress-equalised for 1 hour at 345° C. where relaxation resistance is desired, while Inconel springs should be stress-equalised for 1 hour at 480° C. for services at elevated temperatures.

As previously mentioned, the report of this investigation is given in *Monel Notes No. 26*, copies of which may be obtained on application to Henry Wiggin and Co., Ltd., Grosvenor House, Park Lane, London, W. 1.

The Chemical and Physico-Chemical Analysis of Iron and Steel

Twelve Years' Advancement

By E. C. Pigott

Part II. (Contd.)—Papers Describing the Determination of Single Constituents

Phosphorus

No marked departure has been made from the established practice of effecting combination with the molybdate ion; although many contributors describe colorimetric modifications involving, in some cases, the formation of alkaloid complexes; these processes warrant further development.

In the volumetric procedure, the purer grade of perchloric acid is a very useful solvent for steels rich in chromium, but in the absence of nitric acid it is entirely unsuitable for carbon steels, from which appreciable proportions of phosphorus are evolved as phosphoretted hydrogen.

Etheridge (*Analyst*, 65, 496, 1940) has found that the elimination of titanium (< 1.0%) is unnecessary when the phospho-molybdate is precipitated from strongly acid solution, a condition originally designed to counteract the interference of vanadium, and recently found also to inhibit precipitation of arsenic, even when present in large amounts. Without this modification, removal of arsenic is advisable unless of low content. Formerly, it was assumed that elimination was brought about by digestion of the hydrochloric acid solution of the baked mass with metallic zinc, but it is now known that only a proportion of the arsenic is evolved, with the consequence of high results for phosphorus. Elimination is complete when the solution referred to is evaporated to a volume of 4-5 ml. with 5 g. of ammonium bromide or 10 ml. of hydrobromic acid, provided that perchloric acid has not been used as the initial solvent. In the presence of perchloric acid, complete elimination of arsenic may be effected by treating the cold solution with dilute hydrobromic acid and evaporating to fumes. Where 2 g. of sample has been taken, 25 ml. of perchloric acid (s.g. 1.6) and 80 ml. of (1:4) hydrobromic acid are required. These amounts effectively remove arsenic, even when the content is as high as 0.25%.

1. REVIEWS.

- Arzens. *Bull. Assoc. Tech. Fonderie*, 1931, **5**, 33-8.
- Clenell. *Iron and Steel Ind.*, 1933, **6**, 346, 423.
- Hartmann. *Z. anal. Chem.*, 1934, **97**, 349.
- Milovidova and Glazunova. *Zavod. Lab.*, 1934, **3**, 866.
- Swoboda. *Chem. Ztg.*, 1933, **57**, 938.
- Zav'ylov. *Zavod. Lab.*, 1937, **6**, 1037.
(Gravimetric conversion factor rises slightly with the content.)

2. PRECIPITATION AS PHOSPHO-MOLYBDATE.

- Etheridge. *Analyst*, 1931, **56**, 14-21.
(In alloy steels and cast iron; influence of Ti, Si, Cr, V, and W.)
- Ginsburg. *Zavod. Lab.*, 1935, **4**, 705.
(NaIO_3 in place of KMnO_4 .)
- Gutman and Federov. *Soobsh. Vsesoyuz. Inst. Met.*, 1931, Nos. 1 and 2, 69.
(In W-steels; treatment of HNO_3 -solution with deficiency of NaOH .)
- Gutman and Eremicker. *Zavod. Lab.*, 1939, **8**, 1218.
(HNO_3 reduced with 15 ml. 10% NH_4OH -HCl.)
- Jones. *Analyst*, 1938, **58**, 90.
(In basic iron.)
- Kefel and Berliner. *Zavod. Lab.*, 1935, **4**, 143.
(Gravimetric measurement.)
- Krivonoz. *Zavod. Lab.*, 1937, **6**, 1152.
- Muklina. *Zavod. Lab.*, 1939, **8**, 162.
(HNO_3 method.)

- Neuhaus. *Z. anal. Chem.*, 1936, **104**, 416.
(In FeS; excess NH_4F removed by evaporation with borax.)
- Quadrat and Vcelák. (i) *Congr. chim. ind.*, Nancy, Sept.-Oct., 1938, 631-9.
(Conversion to H_3PO_4 is accelerated by the $\text{Fe}(\text{NO}_3)_3$.)
- Quadrat and Vcelák. (ii) *ibid.*, 592-601.
(In FeP.)
- Quadrat and Vcelák. (iii) *Coll. Czech. Chem. Commun.*, 1938, **10**, 583-92.
(In FeP.)
- Ridsdale. *Analyst*, 1931, **56**, 454.
(Treatment of initial solution with KMnO_4 essential.)
- Seuthe. *Chem. Ztg.*, 1937, **61**, 920.
- Seuthe and Schaefer. *Arch. Eisenhüttenw.*, 1937, **10**, 549.
- Shtokova. *Zavod. Lab.*, 1938, **7**, 1419.
(Gravimetrically, using a sintered glass crucible; NaNO_2 preferable to $\text{H}_2\text{C}_2\text{O}_4$.)
- Steinberg and Smith. *Ind. Eng. Chem. Anal. ed.*, 1941.
(In cast iron; graphite eliminated by $\text{HClO}_4 + \text{K}_2\text{Cr}_2\text{O}_7$.)
- Susano and Barnett. *Ind. Eng. Chem. Anal. ed.*, 1936, **8**, 183.
- Zhakovskaya and Bernshtein. *Zavod. Lab.*, 1934, **3**, 214.
(Use of oxine.)

3. COLORIMETRIC.

- (a) *Photometric.*
- Bogatzki. *Arch. Eisenhüttenw.*, 1938, **12**, 195.
(Phosphovanadomolybdate method.)
- Bursuk. (i) *Zavod. Lab.*, 1939, **8**, 12; (ii) *Ber. Pissarjevsky Inst. physik. Chem. Akad. Wiss. Ukr. S.S.R.*, **12**, 177.
(Reduction of phosphomolybdate with Na_2SO_3 .)
- Hague and Bright. *Bur. Stand. J. Res.*, 1941, **26**, 405.
($\text{HClO}_4 - \text{Na}_2\text{SO}_3 - \text{Am}_2\text{MoO}_4$ —hydrazine SO_4 .)
- Hoar. *Analyst*, 1938, **63**, 712.
(Stannous chloride reduction of precipitated phosphomolybdate.)
- Koch. *Arch. Eisenhüttenw.*, 1939, **12**, 69-80.
(Strychnine molybdate method.)
- Murray and Ashley. *Ind. Eng. Chem. Anal. ed.*, 1938, **10**, 1-5.
(Phosphovanadomolybdate method; violet filter with 3-cm. cell.)
- Pronenko and Kamyanyi. *Zavod. Lab.*, 1941, **10**, 423.
(In iron ores; Na_2SO_3 -molybdate method.)
- Ras'kin et al. *Zavod. Lab.*, 1938, **7**, 860.
(Phosphovanado-molybdate method; ether extraction.)
- (b) *Comparison Methods.*
- Clarke. *Analyst*, 1931, **56**, 518-25.
(Strychnine process; As. interferes.)
- Drozd. *Novosti Tekhniki*, 1936, No. 44, 28.
(SnCl_2 -ether method.)
- Getzov. *Zavod. Lab.*, 1935, **4**, 349.
(Mo-V complex.)
- Miloslavskii and Vavilova. *Zavod. Lab.*, 1935, **4**, 1450.
(Mo-V, and strychnine methods.)
- Pil'nik. *Stal*, 1936, **6**, No. 9, 74.
(Red benzidine complex.)
- Raskin. *Zavod. Lab.*, 1936, **5**, 267-71.
(Ether extraction of yellow complex.)
- Schneerson. *Zavod. Lab.*, 1934, **3**, 21.
(SnCl_2 -ether method.)
- Willard and Center. *Ind. Eng. Chem. Anal. ed.*, 1941, **13**, 81.
(In iron ores; yellow phosphovanadomolybdate.)

Selenium

Amounts in the region of 0.25% are now used to bestow machining properties on the stainless types of steel.

Separation from other constituents may be effected by virtue of the insolubility of the element on decomposition of steels with perchloric acid (S.G. 1.6); a rapid method devised by Marvin and Schumb is based on this property. In a process for alloy steels, evolved by Silverman, initial decomposition with copper ammonium chloride serves to isolate selenium from the bulk of the iron.

The iodometric titration of selenious acid should be carried out in very dilute solution in order to obviate occlusion of iodine by the precipitated selenium.

Coleman and McCrosky. *Ind. Eng. Chem. Anal. ed.*, 1936, **8**, 196.
(Evolution of H_2Se by means of HCl and absorption in KI .)

Marvin and Schumb. *Ind. Eng. Chem. Anal. ed.*, 1936, **8**, 109.
(In 18 : 8 steels initial separation by means of $HClO_4$, followed by iodometric titration.)

Silverman. *Ind. Eng. Chem. Anal. ed.*, 1936, **8**, 132.
(In alloy steel; copper chloride process.)

Silicon

Many contributions deal with spectrographic determination. The dehydration methods described involve only slight departures from well-known procedures, but are somewhat more rapid. In the presence of titanium and zirconium, a solvent consisting of nitric acid and sulphuric acid is preferable, since the phospho compounds of these elements do not then contaminate the silica. Materials rich in chromium should be treated with perchloric acid, which retains the element in solution; sulphuric acid tends to furnish insoluble basic chromium sulphates whilst hydrochloric acid fails to attack chromium carbides. Ferrous metals containing copper, molybdenum, or vanadium require an oxidising solvent. With all these acids, tungsten, tantalum, columbium and boron contaminate the silica. Colorimetric methods, based on the formation of yellow silico-molybdic acid are by no means advantageous for alloy steels, since tungsten, titanium, vanadium and aluminium interfere. The colour due to phosphorus may be suppressed by means of sodium fluoride or tartaric acid.

1. REVIEWS.

Arzens. *Bull. Assoc. Tech. Fonderie*, 1931, **5**, 33.

Charpy. *Compt. rend.*, 1937, **205**, 506.

Fowler. *Ind. Eng. Chem. Anal. ed.*, 1932, **4**, 382.

Keeble. *Iron and Steel Ind.*, 1930, **3**, 367.

Malov et al. *Zavod. Lab.*, 1936, **5**, 665.

Ras'kin and Drozd. *Zavod. Lab.*, 1936, **5**, 400.

2. DEHYDRATION METHODS.

Beuto. *Anal. Soc. espanalis quim.*, 1940 (5), **35**, 100.
($HCl-H_2SO_4$ method.)

Chernokun. *Zavod. Lab.*, 1937, **6**, 749.
($HCl-H_2SO_4-(NH_4)_2S_2O_8$.)

Clauberg and Behnenburg. *Z. anal. Chem.*, 1936, **104**, 245.

Mukhina. *Zavod. Lab.*, 1939, **8**, 162.

Niezoldi. *Chem. Ztg.*, 1932, **56**, 363.

Raab. *CA* 5712, 1937.

($HClO_4$ methods for plain, alloyed and high-speed steels.)

Rozene and Mills. *Chemist-Analyst*, 1939, **28**, 38.
($HCl-HNO_3$ method.)

Taylor. *Indus. Chem.*, 1936, **12**, 373.
($HCl-HNO_3$ method.)

Udozenko and Prokopenko. *Zavod. Lab.*, 1936, **5**, 229.
(Rapid $H_2SO_4-HNO_3$ method for special steels.)

Wolf and Heilingzötter. *Chem. Ztg.*, 1930, **54**, 878.
(Single evaporations give uniformly low results.)

3. COAGULATION (GELATINE) METHODS.

Konevskaya. *Zavod. Lab.*, 1935, **4**, 225.

Shkotova. *Zavod. Lab.*, 1939, **8**, 213.

Stasevich and Derkacheva. *Izvest Rostov Nauch-Issledov. Inst. Prikl. Khim No. 2*, 1937, 79; *Khim Referat, Zhur 1, No 2*, 1938, 102.

4. COLORIMETRIC METHODS (SiO_2 , 12 MoO_3).

(a) Photometric.

Alimarin and Zverev. *Trans. Inst. Econ. Min. (U.S.S.R.)*, 1934, **63**.
(Bibliography of colorimetric methods, 1882-1932; yellow silico-molybdate method preferred.)

Davydov et al. *Zavod. Lab.*, 1939, **8**, 1033.
(Blue silico-molybdate process more reliable than that involving the yellow complex.)

Freund, Dietrich and Schmitt. *Giesserei*, 1937, **24**, 61.
(Lefko instrument.)

Klinger and Koch. *Tech. Mitt. Krupp*, 1935, **3**, 58.
(W, Ti, V and Al interfere in silico-molybdate procedure.)

Pinsl. (i) *Arch. Eisenhüttenw.*, 1934, **8**, 97; (ii) *Arch. Eisenhüttenw.*, 1935, **9**, 223.
(i) Solution of 0.1 g. in HNO_3 treated with H_2O_2 , Na_2HPO_4 , $CaCO_3$ and NH_4 molybdate; (ii) NaF obviates separation of phosphorus.)

Wehrich and Schwarz. *Arch. Eisenhüttenw.*, 1941, **14**, 501.
(Yellow molybdate colouration.)

(b) Visual.

Federov. *Zavod. Lab.*, 1935, **4**, 747.

Pinsl. *Giesserei*, 1935, **22**, 78. *Arch. Eisenhüttenw.*, **8**, 97-109, 1934

5. MISCELLANEOUS METHODS.

Isii. *Sci. Papers, Inst. Phys. Chem. Research (Tokyo)*, 1939, **36**, 491.

(After partial evaporation, silicic acid centrifuged and volume estimated visually.)

Karpov and Savchenko. *Zavod. Lab.*, 1937, **6**, 1051.

(Iron held in solution by oxalic acid, precipitation as K_2SiF_6 and alkimetric titration.)

Marunova-Shadrina. *Trudy Vsesoyuz. Nauch-Issledov. Inst. Metrol. No. 15*, 1937, 15. (In French, 20.)
(Rothé ether separation for nickel steels.)

6. IN FERRO-ALLOYS.

In Ferro-Silicon.

Babaev. *Zavod. Lab.*, 1937, **6**, 645.
(Density curves recommended.)

Bogdanchenko. *Zavod. Lab.*, 1938, **7**, 731.
(Na_2O_2 -fusion; extraction with H_2SO_4 .)

Dymov. *Zavod. Lab.*, 1937, **6**, 359.

Gutman and Rubashkin. *Zavod. Lab.*, 1935, **4**, 292.

Hamelink. (i) *Gieterig*, 1939, **13**, 3, 24, 43, 56; (ii) *Chem. Zentr.*, 1939, **II**, 913.
(Review of methods.)

Klinger. *Arch. Eisenhüttenw.*, 1934, **7**, 551.
(Analysis of high percentage ferro-silicon.)

Ririlov. *Zavod. Lab.*, 1935, **4**, 635.
(Density values.)

Sveshnikov and Smirnova. *Zavod. Lab.*, 1935, **4**, 293.

In Ferro-Chromium.

Babaev. *Zavod. Lab.*, 1938, **7**, 601.
($H_2SO_4-HNO_3$.)

Dolinskii. *Zavod. Lab.*, 1937, **6**, 225.

In Ferro-Tungsten.

Anon. *Rev. brasil. chim.* (São Paulo), 1937, **4**, 312.

Bagdanchenko. *Zavod. Lab.*, 1938, **7**, 1435.
(By conversion to phosphotungstic acid.)

Bardocz. *Magyar. Mernok-Epiteszegylet Kofonye, Havi Fuzetei*, 1938, **12**, 97-121.

Fogel'son and Chernov. *Zavod. Lab.*, 1933, **6**, 37.
(In malleable iron.)

Gerlach. *Arch. Eisenhüttenw.*, 1933, **7**, 353.

Heldhausen. *Metallwirtschaft*, 1937, **16**, 37.

Mandel'shtam et al. *Zavod. Lab.*, 1936, **5**, 295.

Masi. (i) *Met. ital.*, 1938, **30**, 111; (ii) *Chimie et indus.*, **40**, 681.

Prokof'ev. *Comp. rend. acad. sci., U.R.S.S.*, 1941, **29**, 443.
(Stereoscope.)

Sawyer and Vincent. *Proc. 5th Summer Conf. Mass. Inst. Tech.*, 1-7.

Scheibe et al. *Arch. Eisenhüttenw.*, 1933, **7**, 354.

Scheibe and Schöntag. *Arch. Eisenhüttenw.*, 1935, **8**, 533.

Striganov. *Zavod. Lab.*, 1933, **6**, 31.
(In malleable iron.)

Sulphur

The greater portion of development has been with the combustion method, developed by Holthaus in 1924 and based on the earlier work of Vita and Schmitz. A temperature of 1,250° C. is suitable for most irons and steels, but "high-speed" and "18-8" steels require 1,350°-1,400° C. An electrically heated platinum winding on an external tube serves to provide these temperatures economically. Originally, the gases were passed through a solution of potassium iodate with subsequent titration of the liberated iodine, a somewhat empirical procedure. In 1929, Swoboda introduced silver nitrate solution as absorbent, titrating the liberated nitric acid with alkali and using methyl red as indicator. Two years later, Holthaus proposed absorption in hydrogen peroxide, preferring sodium alizarin sulphonate as indicator in the alkimetric titration. On ignition, only an insignificant proportion of sulphur trioxide is formed, and in 1933 Kassler found water to be a satisfactory absorbent, the gases being filtered through sintered glass to remove oxides, and the sulphur dioxide titrated with iodine. In a gravimetric modification, described by Kar in 1935, an alkaline peroxide solution of the gases is acidified and treated with barium chloride.

Many contributors describe modifications of the much-abused evolution method, and attention is drawn to still another source of error—namely, the retention of phosphine

in the absorbent, a current of carbon dioxide being proposed as a means of removal. The aqua-regia oxidation method received no noteworthy consideration, and it is gradually being supplanted by the combustion process.

Meinke's method, involving separation of iron by decomposition of the sample in copper ammonium (or potassium) chloride, was modified in 1934 by Colbeck, Craven and Murray, who recommend the process for cast iron, and the present writer has found it to be most reliable except in the case of phosphoric irons, in which that part of the sulphur in combination with titanium, present in almost all irons, remains undissolved on oxidation.

1. REVIEWS.

- Bettger. *Angew. Chem.*, 1933, **46**, 48-51.
 Blanken. *Chem. Weekblad*, 1933, **30**, 90-2.
 (Combustion method preferred.)
 Colbeck, Craven and Murray. *Foundry Trade J.*, 1934, **51**, 308-10.
 (In cast iron; modification of Meinke's CuAmCl_2 method recommended.)
 Gerke. *Zavod. Lab.*, 1934, **3**, 207-10.
 (In special steels and irons; combustion method preferred.)
 Guedras. *Aciers speciaux*, 1931, **6**, 75-80.
 (Description of various types of apparatus and methods.)
 Holthaus. (i) *Arch. Eisenhüttenw.*, 1931, **5**, 95-100.
 (In alloy steels, especially combustion method.)
 Holthaus. (ii) *Arch. Eisenhüttenw.*, 1935, **8**, 349-55.
 (In ferro-alloys.)
 Hubert. *Chimie et Indus. Special No.*, 230-2. (April, 1934.)
 (In low sulphur irons and steels; evolution method considered satisfactory.)
 Karmaus. *Emailwaren-Ind.*, 1934, **11**, 194.
 Mikhal Chishin. *Kem. Zhur.*, 7; *Wiss.-tech. Abt.*, 1932, 231-21.
 (In cast iron and steel; gravimetric and volumetric procedures compared.)
 Zanker. *Arch. Eisenhüttenw.*, 1931, **5**, 101.
 (In cast iron; six methods examined.)

2. COMBUSTION METHOD.

- Bogdanchenko. *Zavod. Lab.*, 1937, **6**, 369.
 (Kassler's method; with carbon conjointly.)
 Bogdanov. *Zavod. Lab.*, 1934, **3**, 613.
 (Kassler's method.)
 Bhukavii and Markelova. *Zavod. Lab.*, 1938, **7**, 1455.
 (In alloy steels; H_2O_2 , I_2 and AgNO_3 equally good as absorbents.)
 Fogel'son et al. *Zavod. Lab.*, 1934, **3**, 607-12.
 Gerke and Kardakova. *Zavod. Lab.*, 1934, **3**, 977-83.
 (Simultaneous determination of sulphur and carbon.)
 Girard. *Compt. rend. 17me Congr. chim. ind.*, Paris, Sept.-Oct., 1937, 630-4.
 (Kassler's method.)
 Gotta. *Z. anal. Chem.*, 1938, **112**, 7-15.
 Grundberg. *Jernkontorets Ann.*, 1938, 122, 49.
 (Absorption in AgNO_3 and titration with NaOH .)
 Gutman and Gokhfeld. *Zavod. Lab.*, 1935, **4**, 26.
 (In steels and fuels; Kassler's method.)
 Hale and Muehlberg. *Ind. Eng. Chem. Anal. ed.*, 1936, **8**, 317.
 (Gases passed through N_2O_2 and H_2SO_4 titrated with NaOH , using methyl red.)
 Ishimaru. (i) *J. Chem. Soc., Japan*, 1937, **58**, 257-66.
 (Modification of Kar's method.)
 Ishimaru. (ii) *Zippon Kinzoku Gakkai.*, 1939, **3**, 60-6.
 (Absorption in KIO_3 and titration with $\text{Na}_2\text{S}_2\text{O}_3$.)
 Kanomori. *Tetsu-to-Hagane*, 1940, **26**, 630.
 (In pig iron and alloy steels at $1,300^\circ\text{C}$; oxygen flow, 200 c.c. per min.; H_2O_2 absorbent; CO_2 expelled before titration.)
 Kar. *Ind. Eng. Chem. Anal. ed.*, 1935, **7**, 244.
 (Gases passed into Na_2O_2 solution and sulphur finally weighed as BaSO_4 .)
 Kassler. *Chem. Ztg.*, 1933, **57**, 573.
 (Gases collected in water and SO_2 titrated with I_2 .)
 Misson. *Chimie et indus., Special No.*, March, 1932, 326-8; and *Special No.*, April, 1934, 436.
 (Simultaneously with carbon.)
 Rooney. *Analyst*, 1934, **59**, 278.
 (Modification of Holthaus' method.)
 Shishkov. *Zavod. Lab.*, 1932, No., 11-12, 22-3; *Chem. Zentr.*, 1934, **11**, 3993.
 (Absorption in AgNO_3 .)
 Stokanovskaya. *Zavod. Lab.*, 1938, **7**, 1455.
 (Gutman and Gokhfeld.)
 Taylor-Austin. (i) *B.C.I.R.A. Res. Rep.*, 1939, 2037.
 (In cast iron.)
 Taylor-Austin. (ii) *B.C.I.R.A. Res. Rep.*, 1940, 2037A.
 (Description of platinum wound furnace.)

3. EVOLUTION METHODS.

- Brown. *Indus. Chem.*, 1936, **12**, 549.
 (In cast iron and steel.)
 Clarke. *Analyst*, 1931, **56**, 436.
 (In small samples.)

- Feijo. *Rev. chim. ind.* (Rio de Janeiro), 1936, **5**, 103.
 Fogel'son. *Zavod. Lab.*, No. 5-6, 1932, 44-7; *Chem. Zentr.*, 1934, **11**, 3530.
 (Simplification of Schulte's method.)
 Gerke and Kardakova. *Zavod. Lab.*, 1934, **3**, 977.
 Girard. *Compt. rend. 17me Congr. chim. ind.*, Paris, Sept.-Oct., 1937, 630-4.
 (No leads to low results.)
 Hoar and Eyles. *Analyst*, 1939, **64**, 666.
 (Absorbent swept with CO_2 and acidified with ice-cold H_2SO_4 .)
 d'Huart. *Documentation sci.*, 1938, **7**, No. 61, 19.
 (New apparatus proposed.)
 Junghlut. *Ann. chim. anal. chim. appl.*, 1931, **13**, 161-70.
 (Special apparatus; $\text{Cd}(\text{OAc})_2$ absorbent swept with CO_2 to remove P.)
 Krivenko. *Zavod. Lab.*, 1937, **6**, 1152.
 (Schulte's method.)
 Rauch. *Documentation sci.*, 1934, 279; *Chimie et Indus.*, 1934, **33**, 1366.
 Stasevich and Derkacheva. *Izvest. Rostov. hauch-Isledov. Inst. Prikl. Khim.*, 1937, No. 2, 79-83; *Khim. Referat. Zhur*, 1938, **1**, No. 2, 102.
 ($\text{Cd}(\text{OAc})_2$ as absorbent.)
 Tzinberg. *Zavod. Lab.*, No. 11-12, 1932, 43; *Chem. Zentr.*, 1934, **11**, 3826.
 (Evolution method a measure of injurious sulphur.)
 Yamauchi. *Anniversary vol. dedicated to Masumi Chikashige*, 1930, 111-8.
 (In place of annealing, sample heated in hydrogen.)
 Zaffuto. *Atti. congr. intern. chim.*, 1939, **3**, 487.
 (Special apparatus for rapid work.)
 Zeutzius. *Z. Anal. Chem.*, 1939, 116, 102.
 (Solvent consists of HCl , H_2SO_4 and H_2O .)

4. MISCELLANEOUS.

- Evans. *Chem. Eng. Mining Rev.*, 1934, **26**, 426.
 (Rapid method for cinder, etc.)
 Silverman. *Ind. Eng. Chem. Anal. ed.*, 1935, **7**, 205.
 ($\text{CuAmCl}_2\text{-HClO}_4$ method.)
 Stognii. *Zavod. Lab.*, 1936, **5**, 1506.
 (In iron ores; CaCO_3 and fusion and evolution by means of Zn or Al .)
 Zemlyanskii and Razumov. *Zavod. Lab.*, 1936, **5**, 363.
 (In iron ores by Johnson's reduction method.)

Tantalum

An outstanding contribution to modern chemical analysis is the exhaustive study of the separation of tantalum from columbium by Schoeller and his collaborators, resulting in a successful method based upon the differential hydrolytic dissociation between oxalotantalic acid and oxalocolumbic acid in slightly acid solutions containing tannin. A full account is given in Schoeller's book, "The Analytical Chemistry of Tantalum and Niobium" (Chapman and Hall, Ltd., 1937). The method has been applied to stainless steels by Cunningham (*Ind. Eng. Chem. Anal. ed.*, 10, 283 (1938)), who describes a cupferron method in the same paper. A photometric process employing hydrogen peroxide has been evolved by Klinger and Koch (*Arch. Eisenhüttenw.*, 13, 127 (1939)). Thanheiser (*Mitt K.W. Inst. Eisenfor.*, 22, 255 (1940)) measures the yellow coloration produced with pyrogallol. Fueke and Daubländer (*Tech. Mitt. Krupp.*, 2, 174 (1939)) have applied precipitation with (a) benzenearsonic acid, and (b) NzNCO_3 . Spectrographic determination has been described by Holzmüller (*Z. Anal. Chem.*, 115, 81 (1938)), by Klinger and Koch (*Tech. Mitt. Krupp.*, 2, 179 (1939)) and by Schliessmann (*ibid.*, p. 185). Estimation in pig iron and cast iron is discussed by Taylor-Austin (*B.C.I.R.A. Res. Rep.* 6033 (1939)).

Tellurium

This element has now established applications as an addition to steel and cast iron, bestowing fluidity and free-cutting properties. It is claimed that 0.001-0.01% in cast iron maintains carbon in the combined form during pouring and solidification. Both tellurium and selenium are precipitated from hydrochloric acid solutions by reducing agents (e.g., sulphur dioxide), but from strongly acid solutions, only selenium is obtained, and this is the usual method of separation. In a method for estimating tellurium in steel, described by Deiss and Leysaht (*Z. anal. Chem.*, 105, 323 (1936)), sulphur dioxide and potassium iodide are the precipitants. Nusbaum and Hackett, *J. Optical Soc. Am.*, 31, 620 (1941) describe a spectrographic method.

(To be continued.)

Desulphurisation in the Open-Hearth

Investigations are described on the desulphurising power of calcium silicate steelmaking slags, as affected by their iron oxide contents.

MANY chemical reactions occurring between the slag, metal and gas in steelmaking processes do not reach equilibrium on account of their slow rate. Some of the reactions, however, actually attain a state of equilibrium, and an accurate determination of the equilibrium state of any chemical reaction gives the limits the reaction will eventually attain. Recently, F. W. Scott and T. L. Joseph¹ have made a study on the effects of iron oxide on the desulphurising power of calcium silicates at equilibrium. The rate of the reaction itself is not dealt with, but the effect of temperature on the equilibrium is considered.

The investigation was carried out to determine the effect of slag constituents, silicon, lime and iron oxide upon the distribution of sulphur between slag and metal. The effect of temperature upon this distribution was also studied over the entire steelmaking range of 1,550° C. (2,822° F.) to 1,675° C. (3,047° F.). As very basic slags, with lime-silica ratios over 2, have high melting points, the basicity of the slags was necessarily restricted to those which are molten between 1,550° and 1,675° C. Simple slag systems were formed from mixtures of pure lime and pure silica in proper proportions to form one of the following silicates:—

$\text{CaO} \cdot 2\text{SiO}_2$; $\text{CaO} \cdot \text{SiO}_2$; $3\text{CaO} \cdot 2\text{SiO}_2$; and $2\text{CaO} \cdot \text{SiO}_2$.

To facilitate the melting of these slags, Fe_3O_4 was added in each case. All melts were made under an atmosphere of commercial nitrogen gas, and a sufficient number of tests, usually three, were made with slags of each basicity to determine the effect of temperature upon the distribution of sulphur between the slag and the metal. The concentration of iron oxide in the slags was controlled through the degree of oxidation of the bath, and conditions were established to maintain three degrees of oxidation. For the most oxidised condition, Armco ingot iron was melted and no additions were made to the metal, and for the other two conditions, either silicon was added to maintain a residual silicon content ranging from 0.2 to 0.5%, or to eliminate practically all the FeO from the metal it was saturated with carbon, the amount of carbon present being a function of the temperature.

A rotating induction furnace² was used for making the investigation, and all tests were made using a bath of Armco ingot iron as a base. Sulphur in the form of iron sulphide was added to the molten metal to raise the sulphur content to approximately 0.10%. After the bath was melted and had reached the desired temperature, it was rotated at 400 r.p.m. to form a metallic cup, in which the slag-metal reactions were carried out. A briquette made of the powdered slag constituents necessary to form a slag predetermined composition was dropped into this cup, melted and held for an hour to attain equilibrium conditions. To obtain data representing equilibrium conditions with respect to sulphur distribution between slag and metal at a definite temperature, it was necessary to remove the slag from the surface of the metal and to chill it to prevent any change in composition, and this instant chilling and the freezing of the equilibrium was accomplished by drawing the slag into a graphite cup.

From the experimental data obtained in the investigation the index of basicity based on the molecular concentrations of lime and silica, the sulphur distribution coefficient obtained by dividing the percentage of sulphur in the slag by the percentage of sulphur in the metal, and the equilibrium constant were determined for the various slags in their different degrees of oxidation. As the various tests

were not made at even temperature increments, due to operating difficulties, results were correlated at definite temperatures, 1,575°, 1,600°, 1,625°, 1,650°, and 1,675° C. by interpolation and extrapolation.

When the relationship of slag basicity to sulphur distribution coefficients was considered at the various temperatures, it was found that when the index of basicity was less than unity the effect of temperature as well as the degree of bath oxidation upon the desulphurising power of the slag was small. When the index of basicity, however, was equal to or exceeded unity, both temperature and the degree of bath oxidation had a pronounced effect. Under oxidising conditions at 1,600° C., the values of the sulphur distribution coefficients ranged from 0.200 to 0.811, as the basicity index increased from 0.488 to 1.668. Under strong reducing conditions at the same temperature, the values of the sulphur distribution coefficients ranged from 1.274 to 197.0 as the basicity index increased from 0.665 to 1.823. This tremendous change in desulphurising power of the slags is considered due to the comparatively small change in the amount of FeO in the slag. In a metal bath containing silicon and representing an intermediate stage of bath oxidation, sulphur distribution coefficients ranged from 0.227 to 3.680 as the basicity index increased from 0.381 to 1.584.

The data on the relationship of the concentration of iron oxide in the slag to the sulphur distribution coefficient showed that the introduction of silicon and carbon into the metal bath increased the value of the sulphur distribution coefficients and that this increased desulphurising power of the slag was due to the reduction of the iron oxide in the slag. This effect of iron oxide on the desulphurising power of a lime-silica slag is of the greatest importance, as small amounts of iron oxide in a basic slag reduce its desulphurising power considerably. Iron oxide in the slag was found to exert a much greater influence than changes in basicity or changes in temperature.

The relationship of slag basicity to the sulphur distribution equilibrium constant with controlled oxidation conditions of the metal bath showed that a considerable amount of FeO was combined as silicate when the basicity was less than unity, but when the basicity was unity or higher little or no iron oxide existed as silicate. It was also thought that in the more basic slags the iron oxide might be considered to be "free" and to affect the desulphurisation of the metal. This was indicated by the close agreement in the equilibrium constants which were determined under oxidising conditions for all the slags except the $\text{CaO} \cdot 2\text{SiO}_2$ series. It was also found with the silicon-deoxidised bath that a considerable proportion of the combined FeO as well as the "free" FeO was reduced, and that this reduction of iron oxide tended to increase the acidity of the slag, and by so doing to reduce its desulphurising power. The effect of increasing temperature was to increase the desulphurising power of those slags and the value of equilibrium constants also increased as the temperature increased. This increase in equilibrium constant indicated that the reaction was endothermic and was favoured by higher temperatures.

In general, iron oxide had a greater effect than any other factor upon the desulphurising power of a basic slag, and the sulphur distribution coefficient was increased more than 200 times when the iron oxide was reduced by saturating the steel with carbon. When the lime-silica ratio exceeded unity, substantially all of the iron oxide in the slag appeared to be free and accordingly was active in controlling the iron oxide in the metal and the desulphurising power of the slag. The value of the sulphur distribution coefficient showed a slight increase, with increase in temperature, and the equilibrium constant also increased with temperature, which indicated that the desulphurising reaction was endothermic and was favoured by higher temperatures.

¹ *Metals and Alloys*, 1942, vol. 13, No. 5, pp. 745-750; No. 6, pp. 976-978.
² *METALLURGIA*, 1942, vol. 26, No. 132, p. 78.

Reviews of Current Literature

An Introduction to Aeronautical Engineering.—Vol. III.

Properties and Strength of Materials (Metals).

THIS volume is one of a series specially written for those engaged in practical aeronautical engineering, and who feel the need of, at least, an elementary knowledge of the theory underlying their practical work. It deals briefly with the principal metals used in the construction of aircraft and the methods of determining the sizes of the members from the loads in them.

The first edition was published in 1933, and this volume is the fourth edition, an indication that it supplies a need for the aeronautical student for whom it was primarily written. Since the first edition several alterations and additions have been made, thus reference is now made to nitriding, normal stress, torsion test, principal stresses, Wagner beam, and elastic instability of struts. In its present form the book deals with the structure of pure metals and alloys, solidification and heat-treatment; alloy steels and light metals are discussed; strain, stress and elasticity; mechanical properties and testing of materials; riveted joints, wiring lugs, thin cylinders; torsion; beams and struts of various kinds. In an Appendix some useful constants are given of standard sections; an apparatus for making torsion tests is described, and many useful test examples are given which the student will find valuable.

The value of this book is not confined to aeronautical students; it should prove of equal value to students in any branch of mechanical engineering. The matter is presented in a form which should be readily assimilated by the average engineering student.

By J. D. Haddon, B.Sc. Published by Sir Isaac Pitman and Sons, Ltd., Parker Street, Kingsway, London, W.C. 2. Price 8s. 6d. net.

Steels for the User.

THERE is available in normal times a very large number of constructional materials, and their properties tend to increase in intricacy with time. To facilitate proper selection from these materials, the engineer needs a metallurgical training; however, he is not sure of this question of metallurgy and frequently ignores it. To ensure more rapid progress in engineering practice, it is probable that a more general effort will be made to incorporate a useful metallurgical training in the education of future engineers. Until a more generous measure of training in metallurgy is included in engineering curriculum the engineer will be forced to rely on his own experience, supplemented by information gleaned from books. The vast majority of books on metallurgy, however, are written for the metallurgist, and are too complex for the average engineer, but this book is an important exception.

The engineer should have a passing knowledge of the various methods by which steel is produced, such as the Bessemer, open-hearth and electric processes, though the bulk of steel is produced by the open-hearth process. In all processes the steelmaker strives to obtain uniformity in each ingot of steel he produces, because the designer of any structure, in calculating the stresses in a piece of steel, must assume that the material is uniform in properties. Unfortunately, nature has other ideas, and materials can assume form without uniformity. The structure and properties of a steel ingot vary considerably. The properties depend upon a composition involving carbon, silicon, manganese, sulphur, phosphorus and probably other alloying elements, such as nickel, chromium, molybdenum, etc., but casting conditions, such as temperature, rate of pouring, method of pouring, change of volume, and escape of gases also enter into the determination of the structure of the resulting metal. Subsequent treatment of the steel

to prepare it into the various forms and conditions for the user also have a considerable influence on the structure and properties of the steel. It is, therefore, remarkable, and certainly a tribute to the steelmaker, that so many tons of steel is received in good faith and passed on to constructional work, but the engineer should have a passing familiarity with different methods of production and with the metallurgy of steel.

There is some evidence that this book meets this need; the first edition, published in 1937, was exhausted in just over three years. The present edition has been greatly augmented with new matter, and a more complete treatment of other sections. The various sections comprise mechanical quality and its assessment; specified requirements for commercial steels; the effect of composition upon mechanical quality; bright and free-cutting steels; the heat-treatment of steel; industrial heat-treatment of low-carbon steels; the heat-treatment of high-carbon steels; case-hardening and similar treatments; the use of steel at elevated temperatures; fatigue testing; weld-testing and treatment; and the general principles of selection.

This book is essentially practical, and the author is to be congratulated on the able manner in which the matter is presented. The substantial additional information given in this edition, particularly that on weld-testing and treatment, makes the book invaluable to engineers, to whom we have no hesitation in recommending it as a means of gaining that familiarity with the metallurgy of steel which is so desirable.

By R. T. Rolfe, F.I.C. Published by Chapman and Hall, Ltd., 11, Henrietta Street, London, W.C. 2. Price 25s. net.

Engineering Questions and Answers.—Vol. III.

FOR many years a "Questions and Answers" section has been a useful feature of the *Mechanical World*, and as a result of frequent requests by readers of that journal, selected answers to questions commenced to be published in book form. This book is the third volume, and one is immediately impressed by the diversity of the questions asked and the full and informative manner in which answers are given. The value of the collection lies in the fact that the questions all arose originally out of the difficulties and problems encountered by engineers in the course of their work, and the publishers are justified in thinking that the continuance of the record in a convenient form for reference will be of real service.

As in previous volumes, a comprehensive index is printed at the beginning of the present volume, and readers will find it very convenient for reference.

Published by Emmott and Co., Ltd., 28, Bedford Street, London, W.C. 2, and 78, Patatine Road, Manchester, 20. Price 6s. net.

Tin Solders

THE need for economy in tin makes it necessary to consider where and how the composition of tin solders can be modified with this object. Changes of this kind must be based on a sound knowledge of existing tin solders and their properties. It is therefore of interest that the British Non-Ferrous Metals Research Association is issuing a second edition of its monograph, "Tin Solders." The first edition, written by Mr. S. J. Nightingale, has been thoroughly revised by Dr. O. F. Hudson and brought up to date in the light of investigations carried out in the last 10 years in the Association's laboratories and elsewhere. Important new sections have been added on the creep properties of solders and soldered joints, and the new edition, which will be published immediately, is a book of 118 pp., price 10s. 6d. post free (in the United States \$2.75 post free). It may be obtained from the B.N.F.M.R.A., Euston Street, London, N.W. 1, or from any bookseller.

Constitution of Alloys Bibliography

This bibliography contains over 5,000 references to papers dealing with the constitution of binary, ternary, and more complex alloy systems, both ferrous and non-ferrous. References have been included not only to papers of a purely constitutional character, but also to many X-ray and physical property studies of alloys, which have some bearing on the constitution. The systems are arranged strictly in alphabetical order of the chemical symbols of the metals composing them, and under each system the references are arranged approximately in chronological order, thus the bibliography is presented in a very convenient form. To furnish some guide amongst the references (which in a few systems exceed 100), asterisks have been placed against those in the originals of which a new equilibrium diagram, or portion of one, is to be found. It is intended that this bibliography shall be used in conjunction with the abstracts that the Institute of Metals has published since its foundation, first in its *Journal* and then in its *Metallurgical Abstracts* (Series II); for convenience, therefore, references have been included in these abstracts which will enable the user to decide quickly which papers it is most desirable to consult in the original.

This bibliography is thoroughly up to date, and contains references to all papers seen up to the time of going to press. It will prove invaluable to all research workers in metallurgy, works' metallurgists, and others interested in the constitution of metallic alloys.

Compiled by J. L. Houghton, D.Sc. Published by the Institute of Metals, 4, Grosvenor Gardens, London, S.W. 1. Price, 3s. 6d. post free.

Anodic, Chemical and Paint Finishes for Aluminium and its Alloys

THE high resistance to corrosion of aluminium is second only in commercial importance to its light weight, and may even on occasions become the primary factor on which choice of the metal rests. As in the case of most other non-ferrous metals and iron, however, the corrosion resistance of aluminium decreases as its strength is increased by alloying. This decrease is almost negligible in some alloys of aluminium, but becomes more pronounced in the stronger alloys, particularly those containing heavy metal constituents, including copper. It therefore becomes necessary to protect these materials when the conditions of service are such that attack can take place due to the presence of atmospheric moisture or chemical vapours, and no diminution of strength can be tolerated.

The construction of modern aircraft which embody considerable quantities of strong aluminium alloys furnishes a good example of severity of service in respect of strength requirements, and it was for the purpose of protecting such alloys that the first commercial electrochemical process, namely, anodic oxidation, was developed and patented by Bengough and Stuart in 1924. This process has been widely used for aircraft and other applications, and since its introduction a number of variants of the process have been introduced having the same underlying principle. In addition chemical treatments have been evolved, and protection of a high order can be ensured by application of suitable paint systems.

The various anodic oxidation processes which may be applied to aluminium and its alloys are discussed in a recent bulletin, which also outlines briefly the chemical and paint procedures. Particular attention is given to the anodising process which produces a strong oxide film on the aluminium-alloy components treated that offers strong resistance to atmospheric attack and that of a large number of chemicals. The Bengough-Stuart process and the Alumilite process are considered, and reference is made to the Eloxal process, while the brightening process, such as the Alzak and the Brytal processes, are briefly outlined. Of considerable interest are notes on operation

of anodising processes, these points of major importance are detailed in an informative manner. Reference is also made to various chemical treatments, to etching, and to painting practice.

The information given in this bulletin is of a very useful character, and it is presented in an easily readable form; it is published by Northern Aluminium Company Ltd. Banbury, Oxfordshire, and copies may be obtained gratis on application.

The Polarographic Method of Analysis

IN recent years the polarographic method of analysis has been introduced with marked success into industrial and research laboratories because of its immense possibilities, not only as a tool for research, but also as a convenient and quick method of routine micro-analysis. In view of the greatly increased interest in this method, a recent publication dealing with the Cambridge Polarograph is particularly noteworthy. This publication is unique in its thorough treatment of the general principles and technique of polarographic analysis, in the large number of actual records reproduced from original polarograms, in the tables of half-wave potentials, as well as a chart of half-wave potentials, and a bibliography of 168 selected references.

While it is not intended to be a comprehensive treatise on polarography, the information contained in this publication is extremely valuable as an introduction to the subject. The instrument and general principles are described in some detail, and examples of important analyses are given, which will enable those interested to determine the possibilities of the instrument as applied to particular problems. This useful publication, of 36 pages in demy 4to, is admirably produced, and copies may be obtained on application to Cambridge Instrument Co., Ltd., 13, Grosvenor Place, London, S.W. 1.

Melting Furnaces For Grey Cast-Iron

A COUPLE of years ago the Melting Furnaces Sub-Committee of the Technical Committee of the Institute of British Foundrymen issued a special report on melting furnaces for cast iron; this has now been released for general publication. The report is concerned with the melting of grey cast-iron and includes very complete information on crucible furnaces, air furnaces, electric furnaces, rotary furnaces, and cupola furnaces. The information given on these various types of furnaces is authoritative and reliable, it includes operation and performance of each, and metallurgical considerations are discussed. Since the cupola is more generally used as a melting appliance in iron foundries, more attention is given to this type of furnace. A comparison of melting costs is given in the concluding chapter.

Published by the Institute of British Foundrymen, St. John Street Chambers, Deansgate, Manchester, 3. Gratis to members; 10s. 6d. to non-members; and 5s. to students attending recognised technical schools.

The Case-Hardener's Handbook

THE object of this booklet of 26 pages is to present in compact form such information and data likely to be useful to those engaged in the commercial case-hardening and heat-treatment of steel, and in such a limited space a surprising amount of information is given. Attention is directed more particularly to case-hardening, and while mention is made of several methods, information is given especially on pack-hardening in boxes in which compounds can be used repeatedly with additions of new material to replace losses in service. Heat-treatment, quenching, tempering, selective hardening, faults in case-hardening, hardness testing, and furnaces are some of the subjects briefly discussed, while specifications of the more commonly used case-hardening steels are given. This useful little booklet is published by Piftin, Ltd., Exhibition Grounds, Wembley, Middlesex, price 1s.

The Effect of Minor Alloying Elements on Aluminium Casting Alloys

Present conditions have made great demands on the producers of primary aluminium, and it has become necessary to make greater use of remelted metal; in order to do so many specifications have been modified to permit the re-use of aluminium and its alloys. With both primary and secondary aluminium so-called impurities are taken into the alloys, and the actions and effects of unwanted alloying elements are discussed in connection with the copper and copper-silicon aluminium alloys.

WITH the ever-expanding metal requirements to meet war-time demands, the need for the conservation of metals has become very real, and every effort must be made to apply our resources to the best advantage. This refers to scrap as well as to new metal, both of which constitute the stock from which supplies are obtained for the vital products needed. In remelting scrap, however, it is often unavoidable that unwanted metallic and non-metallic elements are included in the resulting metal; in some cases these can be removed by relatively simple operations, either by furnacing, distilling or electrolytically, in others the cost is too great to make it commercially practical. Aluminium and its alloys are included in the latter. Even in the production of virgin aluminium, it is expensive to purify it to a content of 99.9%, and the purest commercial aluminium still contains a total of about, 0.2 to 0.3% of such elements as iron and silicon, while several other elements are present in smaller amounts. Obviously, therefore, during the remelting of scrap, even under the strictest methods, unwanted elements are associated with the metal. The resulting aluminium alloy may contain such elements as copper, zinc, manganese, magnesium, iron, chromium, nickel, silicon, lead, tin, bismuth, titanium, and, if sodium and calcium be added, there are about 14 common elements which may be desired elements, innocuous or harmful.

Since unwanted minor alloying elements cannot be readily removed from aluminium, it is necessary to use these alloys to the best advantage, especially under the present existing shortage of virgin aluminium. Remelted aluminium has, of course, been successfully used for many years, but its full use has been restricted by specifications, many of which stipulated virgin aluminium. Modifications have since been made, however, and its application for many purposes is not now so limited as formerly. The main trend now seems to be to determine how many and what amounts of these minor elements can be present without affecting the properties of aluminium alloys adversely.

Investigations on the effect of minor alloying elements on aluminium casting alloys have mainly been concerned with aluminium of high purity rather than complex compositions obtained when scrap is remelted, but an important contribution to the subject is given by Bonsack,* who considers their influence (1) in respect to the physical properties, and (2) in respect to the corrosion properties.

The physical properties should be relatively easy to analyse, while the corrosion resistance is difficult, because no standard tests are available which repeatedly give the same answer; a few test methods which give information are of value for comparison in studies of alloys, but are not necessarily a reliable guide for actual service requirements. In present practice it is customary to use protective coatings on aluminium alloy castings that are subjected to corrosion; thus, while this aspect of the problem is important, it is not so important as the physical properties, which can be accurately measured, and which provide data directly usable for designing. With this in view it is generally more important to be well informed regarding the effect of these minor alloying elements on the castability,

machinability, tensile strength, yield strength, proportional limit, elongation, impact strength, heat-treatability, and stability at elevated, subnormal and room temperatures.

With these considerations in mind two main groups of casting alloys can be distinguished: the aluminium-copper alloys and their derivatives, the aluminium-silicon alloys and their variations. In the copper-alloy group, 1.5, 4.5, 7.5 and 10% copper alloys are regarded as the subdivisions in the aluminium-silicon alloy group the subdivisions, are 3, 5, 7.5 and 12% silicon. The first group includes the aluminium-copper, aluminium-copper-silicon, and aluminium-copper-nickel alloys, and it is on these alloys that the influence of unwanted alloying elements is discussed in this article; in a later issue it is hoped to present information on their effect in the aluminium-silicon base alloys.

8% Copper Alloy

The original composition of this alloy was 8% copper and 92% aluminium, iron and silicon being present as impurities. This alloy is difficult to cast, its fluidity is not very good, and it is somewhat hotshort. The addition of more silicon improves the castability of the alloy. The two elements, copper and silicon, are desired in the alloy; all other elements are to be considered "impurities."

The most common undesired element is iron; with aluminium and other alloying elements it forms complex intermetallic compounds. These compounds have, in general, very low, solid solubility in aluminium, and crystallise either in needle or plate form, or in skeleton dendrites. Like most metallic compounds, they are brittle and reduce the ductility of the aluminium-copper-silicon alloy, the degree depending on the amount present and on the size and types of crystals formed. The size and form of these crystals depend mainly on the chill obtained during solidification, and for die-casting the alloy can contain a higher percentage of iron. Sand castings, however, cool relatively slowly, and when iron is present in amounts of 1.5% relatively low ductility will result, and also low strength. For good commercial sand castings, where a fairly good ductility is desired, the iron content should not exceed 1.3%.

Iron, however, has some good points. It decreases the hot shortness of the alloys, improves the tensile strength, and hardness slightly, and preserves strength at elevated temperatures. In combination with silicon in aluminium-copper alloys it has been found to be desirable, but this is only true when the silicon content is low—less than 1.5%. If the silicon content is higher, the proportion of iron to silicon is no longer important, since the higher silicon content causes a similar improvement in the alloys as iron does in low silicon-containing copper-aluminium alloys. However, too high an iron content in combination with high silicon is also bad.

Magnesium should be limited to a maximum of 0.1% in these alloys. It combines with the silicon to form an intermetallic compound Mg_2Si , which is relatively soluble in the solid aluminium. The solubility increases with increasing temperature, and amounts to about 1.75% at the eutectic temperature. By rapid cooling, some of this compound is kept in solid solution. In this condition it is unstable, and

* W. Bonsack, A.S.T.M. Bulletin, No. 117, 1942, pp. 45-59.

tends to revert to the stable state by precipitating the Mg_2Si in an ultra-fine dispersed form, which is accompanied by a general rapid increase in hardness, strength, proportional limit, yield-strength, and an equally drastic decrease in elongation and general ductility. The hardening effect is the reason for holding magnesium to low limits.

Manganese forms simple and complex compounds with aluminium which have relatively low solid solubility in aluminium. It is a mild "hardener," increases the strength, proportional limit, yield-strength, and hardness slightly with increasing amounts, and reduces the ductility gradually. Its greatest advantages are its effect on the iron-aluminium complex, which, it is stated, changes from the harmful needle into a less embrittling form; it decreases hot shortness and improves the properties of the alloys at elevated temperature. Usually the content of this element is limited to 0.3%, though as much as 0.5% may be present without appreciable effect on the casting properties of these alloys.

Zinc is permitted to be present as high as 2.5%. The solid solubility of zinc in aluminium is about 17% at room temperature, therefore its hardening effect in amounts as low as 2.5% is mild. It increases tensile strength, yield-strength, proportional limit, and hardness somewhat, without decreasing the ductility noticeably. It improves the machinability of the alloys and in amounts up to 2.5% is said to improve castability.

Of other elements likely to be present those most frequently found are nickel, tin and lead. In die-casting alloys in this group, nickel and tin may be specified in amounts limited to 0.5 and 0.3% respectively. Nickel forms an intermediary compound of Al_3Ni with aluminium, and in aluminium-copper-iron alloy forms complex compounds. Nickel hardens and strengthens, but also reduces ductility slightly—about on the order of copper and manganese. It is slightly soluble in aluminium at room temperature. It is said to decrease hot shortness and helps to retain strength and hardness at elevated temperatures. Tin does not form intermetallic compounds with aluminium. It is not soluble in it, but forms a simple eutectic with it. Its low melting point tends to increase hot shortness, therefore its amount must be limited to about 0.5% or even 0.3% or less where hot shortness is a definite problem. To some extent the hot shortness due to tin can be compensated for with silicon. Lead does not mix with aluminium, in small amounts of less than 0.5% it is usually found in the grain boundaries as small globules. Its low melting point, especially when in combination with tin, causes hot shortness, and it has been found that about 0.7% of lead plus tin are the maximum limits for sand and die-castings. When present in the above limits lead does not influence fluidity nor the physical properties to any detrimental extent, but it improves the machinability of the alloys considerably.

10% Copper-Magnesium Alloy

This alloy has long been used as a piston alloy. The main constituents are copper, iron, silicon, and magnesium. Copper at 10% gives high hardness and strength at room and elevated temperatures. Iron and silicon add to these properties as well as magnesium. The change in properties caused by these elements are the same as discussed above; magnesium, however, in this alloy is an important desired element and makes possible the hardness which is obtained by proper casting and subsequent heat-treatment. When properly heat-treated this alloy has hardness in the range 100-140 Brinell, good machinability, and good bearing qualities.

Manganese imparts the same properties to this alloy as mentioned earlier, and has marked advantage even up to 1%, since it improves hardness and strength at elevated temperatures. It should be limited only by the fact that it decreases fluidity, but up to 0.7 to 0.8% the alloy casts without undue difficulty.

Nickel imparts about the same properties as manganese and can be used in greater quantities. In the alloy for die-casting it is limited to 0.03%, and in sand castings to even less, though it can be used in much higher amounts, such as 0.5 or even 1%.

The great objection to zinc is the belief that it causes hot shortness, and therefore weakness at elevated temperatures. For this reason zinc is limited to 0.2-0.5% in these alloys, with the lowest limit for sand-casting alloys, but it may be present up to 0.4 or 0.5% for chill-casting, despite the fact that chill castings are much more troubled by hot shortness than sand castings. Tests on the effect of zinc on the 10% copper alloy conducted by Bonsack gave the following results:—

Zinc, %.	Tensile Strength, lb./sq. in.		
	Room Temperature.	302 F.	437 F.
0.10	32,100	30,300	28,600
0.25	32,300	31,500	28,900
0.40	33,500	31,700	28,400
0.79	34,700	31,800	28,200
1.22	33,700	31,600	28,700

The results seem to indicate that zinc up to 1.2% has no deleterious influence on this alloy and can be used in greater amounts.

4% Copper-Silicon Alloys.

These alloys embrace a number in which the silicon content varies according to the method of casting. A maximum silicon content of 1.2% is stipulated for sand castings, but for die-casting the silicon content is increased to 2 to 3%, while for complicated castings the alloy may contain 5 to 6% of silicon. This indicates that silicon is a desirable element when improved castability is wanted.

Magnesium and all the other elements act identically in these alloys as with the alloys previously mentioned. The ductility, however, is greatly influenced by the presence of magnesium; hence, when ductility is required, the magnesium content should be low—0.05%. High iron reduces the ductility more than does the presence of other elements, such as manganese, nickel, zinc, and even lead and tin. Small additions of silicon, magnesium, nickel, iron and zinc improve the castability of the alloy, while titanium lowers the elongation. These alloys need titanium as a grain refiner, which indicates that they are difficult to use for complicated castings.

Summary

With certain exceptions, the effect of the minor alloying elements on the mechanical properties of aluminium-copper, aluminium-copper-silicon, and aluminium-copper-nickel alloys is either beneficial or innocuous. The only element which requires rigid control is magnesium. In all these alloys (with the exception of 10% copper and Y-alloy) 0.10% magnesium is the maximum which can be tolerated without causing loss in ductility. In cases where ductility is of prime importance, limitation of magnesium to 0.05% is indicated.

Iron is the next element which must be watched carefully. Since much of the contamination arises through the foundry process, every precaution should be taken to prevent unnecessary iron pickup. This is the more serious as the silicon content increases.

All the other elements, such as manganese, titanium, nickel and chromium in one group, and tin, lead, antimony, bismuth and cadmium in another group, are usually present in small enough amounts, so that there is no harm; in fact, as previously pointed out, in many cases great advantages occur when they are present.

One fact should be stated: that in many cases the presence of the elements mentioned in the above discussion sometimes changes the casting characteristics—and some adjustments in the foundry practice may have to be made

to suit the alloy. In many cases, the alloys have a somewhat lower melting point and greater fluidity, therefore the pouring temperatures can be lowered.

There seems to be a question about what are the important physical properties on which the designer and engineer can rely. In most specifications only a minimum tensile strength and elongation are given which would imply that these two are the only properties which the engineer requires. In many alloys the elongation seems to be of prime importance. It is, however, certain that a casting stressed to an extent of considerably less than one-half of the required 6% minimum elongation could only be used where dimensional stability does not matter. A casting must be strong enough to resist deformation. The measure for resistance to the earliest stages of permanent deformation is the proportional limit and the yield-strength, and not the

elongation and tensile strength found in a fractured test-bar or casting. It appears reasonable to class an alloy having 16,000 psi. proportional limit, 24,000 psi. yield-strength, 34,000 psi. tensile strength, and only 4% elongation superior in regards to dimensional stability under stress to an alloy having only 10,000 psi. proportional limit, 16,000 psi. yield-strength, 34,000 psi. tensile strength, and 8% elongation. Differences of this order are commonly found between remelt aluminium alloys and primary alloys. Remelt alloys usually exhibit the greater proportional limit and yield-strength and somewhat lower elongation. It therefore seems advisable to supply the designing engineers with data on proportional limit and yield-strength, in addition to information on tensile strength and elongation. If these data were made available for aluminium alloys, the question of composition would be simplified.

Purging Controlled Atmosphere Furnaces

In view of the danger of explosion when using commercial atmospheres in heat-treatment furnaces, it is customary to purge a furnace of its air before bringing to a high temperature and, to ensure that the danger of explosion has been passed, various methods are used to check the furnace atmosphere. This purging operation is discussed and an apparatus described which permits quick and accurate checking.

OPERATORS of pit or bell type furnaces using controlled atmospheres rich in hydrogen and carbon monoxide recognise the ever-attendant danger of explosion as the result of improper purging. Furnace builders and users alike have evolved operating procedures intended to overcome this hazard, and it is common practice to purge a furnace of its air before bringing it to a high temperature, by passing the combustible gas mixture through it until the gas/air ratio is above the explosive range. Actually, purging is usually carried beyond this point, since there is no accurate checking method in common use, and this excess purging, which is continued after the danger of explosion has been passed, represents a waste of time and of gases. The operation of purging has recently been discussed by F. B. Leslie,* and an apparatus described which allows of the quick and accurate checking of the extent of purging, thus reducing the explosion hazard as well as saving production, time, and materials.

TABLE I.—SPECIFIC GRAVITIES OF TYPICAL CONTROLLED ATMOSPHERES.

Type of Atmosphere.	Composition.					Specific Gravity.
	CO ₂ .	CO.	H ₂ .	CH ₄ .	N ₂ .	
Incomplete combustion ..	6.0	9.6	10.3	0.5	73.6	0.913
Incomplete combustion + secondary cracking	2.0	16.2	23.8	0.7	57.3	0.765
Catalytic cracking	1.1	18.2	34.6	0.6	45.3	0.663
Dissociated NH ₃	—	—	75.0	—	25.0	0.294
30% dissociated NH ₃	—	—	22.5	70.0	7.5	0.504
			NH ₃			

The dangerous constituents in commercial atmospheres are hydrogen, carbon monoxide and methane, the latter as a rule being present in low concentrations. At the start of the purge, the furnace contents are not explosive because the combination of combustible gases is below the lower explosive limit, but as purging progresses, the lower explosive limit is reached and the hazard is present until the combustible gas content exceeds the higher explosive limit for the atmosphere gas being used. When the controlled atmosphere contains sufficient combustible gases to impart explosive possibilities, it is also found that their presence causes the overall specific gravity of the atmosphere to be less than 1.0. In Table I are given typical atmospheres together with their specific gravities. It is evident that since the relative density of air and of the atmosphere gas differ, it is possible to measure the proportions of air in the

furnace gases by comparing the specific gravity of the outlet mixture with the specific gravity of the atmosphere gas entering the furnace. One method, therefore, of testing for safe purging resolves itself into measuring the specific gravity of the outlet gases and continuing the purge until the specific gravity of the pure atmosphere gas is reached.

Some furnaces are "double purged," first with an inert gas and subsequently with the controlled atmosphere gas, the purpose being to remove all oxygen before introducing combustible gases. The inert gases are commonly prepared by burning fuel gas with the theoretical air supply, thereby producing a carbon dioxide-nitrogen mixture, the specific gravity of which is above 1.0. The specific gravity of the outlet mixture is then used to indicate when complete air removal has been effected, and it may also be used on the second purge to indicate when the controlled atmosphere has completely removed the inert purging gas.

For safe purging two points require to be noted. First, it should not be misunderstood that the minimum safe purging time can be determined once and then repeated as a standard rule, but rather that the specific gravity should be measured during every purge. Only by so doing will it be known on every heat when complete purging has been effected, and thus accomplish the time saving without the risk of explosion. Second, in many cases small amounts of air remaining in the furnace may interfere with the heat-treatment even though there might be no danger of explosion. When the specific gravity of the outlet gases is measured, it is readily possible to detect when all the air has been removed so that the heat-treatment is not started until correct conditions prevail, thereby protecting the quality of the work.

In addition to safety, which is of paramount importance, the measurement of specific gravity may be used in the preparation of the atmosphere gas to assist in maintaining uniform composition, thereby improving the quality of the product being heat-treated. When a fuel gas is burned with less air than is required for a complete combustion, the resulting atmosphere usually contains carbon dioxide, carbon monoxide, methane, hydrogen and nitrogen. The composition of those gases depends on many factors, but mostly upon the air/gas ratio, and when this ratio is relatively high, the gas contains a large quantity of carbon dioxide and small amounts of the other gases, and has a comparatively high specific gravity because of the high

* *Metals and Alloys*, 1942, Vol. 16, No. 2, pp. 241-245.

carbon dioxide content. With lower air/gas ratios the carbon dioxide decreases and the carbon monoxide, methane, and hydrogen increases, with a resulting decrease in the specific gravity. It is therefore possible to maintain the correct ratio by measuring the specific gravity of the combustion products. Variations in specific gravity and composition of the raw gas, variations in humidity of gas and air, and variations in temperature or pressure of gas or air may thus be compensated for by adjusting the combustion equipment to produce an atmosphere of constant specific gravity. Variations of 0.1 to 0.2% carbon dioxide and even smaller variations of carbon dioxide and hydrogen may be readily detected by the specific gravity measurements.

Some atmospheres are produced by incomplete combustion followed by removal of the carbon dioxide through chemical absorption or converting carbon dioxide to carbon monoxide by passing the gas through incandescent charcoal. By determining the specific gravity of the generator gas, the air/gas ratio may be verified, and by testing the finished gas, the completeness of carbon dioxide removal or conversion may be investigated. The determination of specific gravity is also desirable in measuring the air/gas ratio in unburned air/gas mixtures, and the same principle may be applied in proportioning fuel gases of different specific gravities, as, for example, natural gas and coke-oven gas. In the same manner, butane-air and similar mixtures, used for heating purposes may be controlled.

When a gas is burned with a very marked deficiency of air in the presence of a catalyst the atmosphere produced is rich in hydrogen and carbon monoxide and contains very little carbon dioxide. The specific gravity will therefore be low, because of the abundance of hydrogen, and if improper operating conditions prevail the gas will contain too much carbon dioxide and too little carbon monoxide and hydrogen and the specific gravity will increase.

If ammonia vapour is heated to about 870° C. (1,600° F.), it cracks to produce an atmosphere of 75% hydrogen, 25% nitrogen. The raw ammonia has a specific gravity of 0.595 and the completely dissociated mixture a specific gravity of 0.295. It is therefore apparent that a high specific gravity indicates incomplete dissociation. Should a partly dissociated mixture be desired, the specific gravity may be used to measure the extent of cracking. A cheaper hydrogen-nitrogen atmosphere may be produced by dissociating ammonia completely and subsequently burning the gas with a deficiency of air. The oxygen of the air burns with the hydrogen to produce water vapour, which is removed and the nitrogen serves to dilute the gas. Depending on the desired dilution, there will be an optimum specific gravity value which should be maintained.

Another important use for specific gravity determinations concerns fuel economy in gas-heated furnaces, such as those using radiant tubes. The combustion is carried out with excess of air, and the combustion products contain carbon dioxide, oxygen and nitrogen. When too much air is supplied a large amount of heat is wasted in the large volume of flue gases which leave at a relatively high temperature. At the same time, the carbon dioxide is low because of dilution by the excess air. As the air supply is reduced the heat loss diminishes and the carbon dioxide increases, with the result that the specific gravity gradually increases until it reaches a maximum with the theoretically correct air supply. Should the air supply become deficient, free hydrogen will appear in the combustion gases and cause a sharp drop in the specific gravity. To obtain the maximum combustion efficiency it is only necessary to adjust the burners to produce flue gases of the highest specific gravity.

A simple automatic instrument for measuring the specific gravity of furnace gases has recently been devised, and consists of a fan which draws in a sample of the gas being tested, sets it in rotation, and creates a torque on a companion impulse wheel located in the same chamber.

This torque, which is proportional to the gas density, is compared with the torque produced by atmospheric air in an identical upper chamber, the impeller of which rotates in the opposite direction. The difference between these opposing torques is a measure of the specific gravity and causes a pointer to move over a scale. The gas sample and air sample are brought to the same temperature and humidity by a humidifier, thus eliminating possibility of error from those sources, while a steel wool filter removes suspended matter and corrosive constituents from the gas if they should be present. In use, the gas samples pass continuously through the instrument at a high rate of flow, and since no time is required for chemical reaction the instrument responds almost simultaneously.

The Production in Rotary Furnaces of Steel for Castings

THE selection of a suitable furnace for the production of steel for castings is not easy, so many factors must be considered before a decision can be made that will satisfy best the conditions in a particular works. Such a decision was made at the Crewe Locomotive Works of the L.M.S. Railway Company, and it is noteworthy that two 5-ton Sesci furnaces were installed for this purpose, particulars of which are given in a recent paper* by F. A. Lemon and Dr. H. O'Neill.

For many years the L.M.S. Railway Company has aimed at the utilisation of the maximum amount of its own scrap in its internal metallurgical processes, and has, simultaneously, obtained satisfactory results with pulverised coal-fired installations. For the manufacture of steel castings a Tropenas converter plant and a 12-ton acid open-hearth plant had hitherto been employed. Other processes were considered, but the method which normally used the minimum amount of pig iron appeared particularly attractive. It is claimed for the pulverised coal-fired rotary furnace that the high working temperature available would give very fluid metal, and heat from exothermic bath reactions, due to the oxidation of pig iron, could be dispensed with. The decision was made to instal two Sesci furnaces, the ultimate aim being to develop a melting-down technique analogous to the crucible process. This requires neither pig iron nor a boiling procedure, and generally relies for the production of killed steel on the content of manganese. That the Sesci steelmaking process had hitherto only worked with an acid lining was offset by the circumstances that good railway scrap, low in sulphur and phosphorus, was available, and it was hoped that, if necessary, a basic lining might ultimately be used.

The furnaces use monolithic acid refractory linings of British origin. The charge consists of 98.5% of railway springs and tyre scrap with not more than 1.5% of pig iron. After numerous experiments the procedure is now to boil, work down and finish in a normal way, though ore additions are seldom required. The authors give details of the properties of the resulting steel and slag, and the working data are compared with those of a 35-ton fixed acid furnace.

Great difficulties were encountered in securing a good life from the refractory linings. With intermittent working this has been raised from a beginning of 29 heats per lining to an average of 125, with a record value of 226. A daily patching technique, developed to enable improved life to be obtained, is described. Chemical, physical and petrographical data of patch and various lining materials are given. It has been found that the most useful lining is one with adequate refractoriness and low after-expansion, but, above all, a facility for forming a durable ceramic bond with the patch repair.

* Iron and Steel Institute, Oct., 1942, Advance copy.

s
r
h
n
y
e
l
f
s
s
s
e

l
f
e
y
a
c
a
t

.